York Mills Collegiate Institute

Physics!

SPH3U
Course Handbook
Fall 2018

Student Name:

Gr. 11 Physics Syllabus

This chart contains a complete list of the lessons and homework for Gr. 11 Physics. Please complete all the worksheets and problems listed under "Homework" before the next class.

	Lesson	Homework
1	Welcome to Physics Course Introduction Group Work	Log on to course website. Homework sheet: *How Groups Work*
2	Group Work, *continued* How to Answer a Question	Handbook: *Learning About Your Brain*
3	Measurement	Handbook: *Measurement and Numbers*, pg. 8

Motion

1	Introduction to Motion	
2	Introduction to Motion, *continued*	Handbook: *Constant Speed*
3	Interpreting Position Graphs	Handbook: *Position Graphs*
4	Defining Velocity	Handbook: *Defining Velocity*
5	Velocity-Time Graphs	Handbook: *Velocity Graphs*
6	Conversions	Handbook: *Conversions*
7	Problem Solving	Handbook: *Problems Unsolved*
8	Changing Velocity	Handbook: *Representations of Motion*
9	Changing Velocity, *continued*	Handbook: *Changing Velocity*
10	Quiz: Representations of Motion The Idea of Acceleration	
11	Calculating Acceleration	Handbook: Finish investigation problems
12	Speeding Up or Slowing Down?	Handbook: *Speeding Up / Slowing Down*
13	Problem Solving Quiz	
14	Area and Displacement	Handbook: Finish investigation problems
15	The BIG Five	Handbook: Finish investigation problems
16	How to Study / Practice Test	
17	Test	

Forces

1	Interactions and Forces	Handbook: *Interactions*
2	What is the Effect of a Force?	
3	The Force-Motion Catalogue	Handbook: *The Net Force*
4	The Change of Force Principle	Handbook: *The Force-Change Principle*
5	The Force of Gravity Quiz: 1st Law + Net Force	Handbook: *Force of Gravity Homework*
6	Normal Force	Handbook: *Normal Forces Homework*
7	Force, Mass and Motion	
8	Force, Mass and Motion, *continued*	Handbook: *Force, Mass and Motion Homework*
9	Newton's Second Law Problem Solving	Problems: finish handbook questions
10	Exploring Freefall	Handbook: *Exploring Freefall*
11	Testing Freefall Acceleration	Handbook: *Freefalling*
12	Interaction Forces	
13	Newton's 3rd law	Handbook: *Newton's Third Law Homework*
14	Friction	
15	Friction	Problem: The LeBron question (E#8) on a solution sheet.
16	Review	
17	Test	

Energy

1	Tracking Energy – part 1	
2	Tracking Energy – part 2	Handbook: *Tracking Energy Homework*
3	Doing Work!	Handbook: *Doing Work Homework*
4	Measuring Energy	Handbook: *Measuring Energy Homework*

5	Changes in Gravitational Energy	Handbook: *Changes in Gravitational Energy*
6	The Conservation of Energy	Handbook: *Conservation of Energy Homework*
7	Power	Handbook: *C:He's Got the Power*
8	Energy Challenge	Handbook: *Energy Challenge, pg.* 98
9	Quiz on Energy	
10-15	Green Vehicle Project	

Electricity and Magnetism

1	The Flow of Electricity	Handbook: *The Flow of Electricity*
2	Models of Current Flow	
3	Electric Energy	Handbook: *Electric Energy*
4	Current and Voltage Laws	Handbook: *Current and Voltage Laws*
5	Resistance and Ohm's Law	Handbook: Resistance and *Ohm's Law*
6	Equivalent Resistance	Handbook: *Equivalent Resistance Homework*
7	Circuit Analysis	Handbook: Complete lesson problems
8	Magnetic Interactions	Handbook: *Magnetic Interactions Homework*
9	Electromagnetism	Handbook: *Electromagnetism Homework*
10	The Domain Theory of Magnetism	
11	The Strong Field Mystery	
12	The Magnetic Field of Loops and Coils	Handbook: *Loops and Coils Homework*
13	The Motor Principle	Handbook: *Motor Principle Homework*
14	Test	

Waves and Sound

1	Good Vibrations	
2	Good Vibrations, *continued*	Handbook: *Good Vibrations Homework*
3	Making Waves	Handbook: *Making Waves Homework*
4	Interference	Handbook: *Interference Homework*
5	The Speed of Waves	Handbook: *Speed of Waves Homework*
6	Standing Waves	Handbook: *Standing Waves Homework*
7	Resonance	Handbook: *Resonance Homework*
8	Sound Waves	Handbook: *Sound Waves Homework*
9	The Propagation of Sound	Handbook: *Propagation of Sound Homework*
10	Resonance in Air Columns	Handbook: *Resonance in Air Columns Homework*
11	Resonance in Air Columns, *continued*	

Test Preparation Strategies

Warning! 90% of preparing for a test is the work you do every day in class and at home. "Studying" for a test the night before or even for a few days before only refreshes your memory – it won't build your understanding or skills by any great amount. Only long-term, careful practice builds them. In our physics course, we test for deep understanding and fluent skills.

(1) **Focus.** Start your test preparation by reviewing each lesson and focusing on the key ideas (often found in handy boxes!)
(2) **Explain.** Explain the key ideas to an imaginary friend by referring to a concrete example (don't just recite a definition).
(3) **Apply.** Prove to yourself that you can apply (use) the key ideas. Find questions from the homework or the investigations that use the ideas. Repeat steps 1-3 for each lesson of the unit.
(4) **Test.** Create a practice test based on questions from the investigations or the homework of the whole unit. Give yourself a time limit. Do not look at your notes, except for a list of equations. Complete the test.
(5) **Evaluate.** Based on your practice test, identify any ideas or skills that you need to improve.
(6=1) **Focus.** Repeat this process with a focus on the areas that need improvement.

Course Website

We now use Google classroom for the grade 11 physics course. Login into Google Classroom with your TDSB account: firstname.lastname@student.tdsb.on.ca

Write down the class code here:

See your teacher to reset your password if needed. Your new password will be SSSSDDMM@Tdsb, where SSSS is first four digit of your student ID, DD is your birth day, MM is birth month.

References

Many excellent resources were adapted to develop the physics lessons in this document. Many other resources inspired ideas here and there. Listing them all would take pages, but here are a few of the most influential ones:

Laws, Priscilla W., and Robert J. Boyle. *Workshop physics activity guide*. New York: Wiley, 1997.

McDermott, Lillian C. *Physics by Inquiry,* Wiley-VCH, August 1995.

Van Heuvelen, Alan, and Eugenia Etkina. *The physics active learning guide*. Pearson/Addison-Wesley, 2006.

O'Kuma, Thomas L., David P. Maloney, and Curtis J. Hieggelke, eds. *Ranking task exercises in physics*. Vol. 26. Upper Saddle River, NJ: Prentice Hall, 2000.

Etkina, E. *Physics Union Mathematics*. http://pum.rutgers.edu/

Knight, Randall D., and Juan R. Burciaga. "Five easy lessons: Strategies for successful physics teaching." *American Journal of Physics* 72.3 (2004): 414-414.

Redish, Edward F., and Juan R. Burciaga. "Teaching Physics with the Physics Suite." *American Journal of Physics* 72.3 (2004): 414-414.

Laws, Priscilla W., et al. *Understanding physics*. New York, NY, USA: Wiley, 2004.

Knight, Randall, and R. Knight. *Physics for Scientists and Engineers: A Strategic Approach with Modern Physics [and Mastering Physics TM]*. Pearson Educaiton., 2007.

Arons, Arnold. *A guide to Introductory Physics Teaching*. New York, NY, USA: Wiley, 1990.

And many, many individual research articles that can be found at: http://journals.aps.org/prstper/

SPH3U: Grade 11 Physics
University Preparation

An Inquiry-Based Course
Welcome to the wonderful world of physics! SPH3U is an introduction to the world of physics and a prerequisite for the grade 12 course, SPH4U. This course is designed according to the principles of Physics Education Research which clearly demonstrate the power of learning through inquiry in a collaborative group format. Major Canadian and American universities (U of T, McGill, McMaster, MIT, Harvard, Stanford and more) are transforming their introductory physics courses by reducing or eliminating traditional lectures and replacing them with engaging activities that have a deep conceptual and practical focus.

Homework
The majority of the class time will be spent doing activities and discussing physics with your colleagues. At home you will be responsible for solving problems using our solution format. You should expect about 30 minutes of physics homework per day on average. Homework problems will be randomly submitted for assessment. Optional textbook readings, online lessons and resources are listed in the syllabus for each lesson.

Assessment and Evaluation
Due to the central role of group work in this course, the work you do in class will account for an important portion of your mark. Daily work will be randomly handed-in and assessed. To help ensure that individual students are pulling their weight in groups, there will be regular quizzes and tests. There is a final exam that covers the entire course material and a major project that will be announced halfway through the course.

Mark Breakdown
The categories of *Knowledge and Understanding* (K/U), *Thinking and Inquiry* (T/I), *Communication* (C), and *Application* (A) are a component of most of the assessments used in this course – however some focus on certain categories more than others. The basic mark breakdown for the course is 70% term work and 30% final examination. The term mark is composed as shown in the chart to the right.

K/U	28%	Tests (usually 3 tests)
T/I	14%	Daily work (7%) (3-4 collected) Regular quizzes (7%) (3-4 quizzes)
C	14%	Tests (8%) (usually 3 tests) Homework Assignments (6%) (7-10 collected)
A	14%	Project(s)

Attendance and Punctuality
Students who are absent are responsible for determining what was missed and making sure that they are caught up *before* the following class. If possible, please speak to your teacher in advance.

Missed Tests
If you miss a test you **must**:

- Let your teacher know in advance if it is due to a pre-arranged reason (i.e. appointment for surgery)
- Call in to the school so your name goes on the daily “Absent List” in the main office.
- Find your teacher immediately after setting foot in the school upon your return.
- Do not discuss the test by any means with your colleagues.
- Be prepared to write the test immediately, at your teacher’s discretion.

Please Read This Document!
Please sign below signifying that you have read this course description.

___________________________________ ___________________________________

Signature of parent, or student if 18 and over   Print name

SPH3U: How Groups Work

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

A: Welcome to Your Group!

1. **Choose Roles.** Each group member will choose the role they will perform at the start of every class. Every day, you will choose a different role. Record each group member's name in the box to the right showing who is performing what role**.** If there are four people in a group, the fourth person can write their name on top of the box: that person is the motivator. **Circle your name.**

Manager*: Ask the speaker to read out loud the instructions and the following questions.*

Working well in a group is a like acting in a play: we all have roles to perform and we can learn perform them well with regular, careful practice. Most colleges, universities, and businesses consider the ability to work well in a group a top skill, so let's start practicing now! In physics class, group work encourages students to discuss and explain their ideas, which is the best way for most people to learn physics.

B: The Bouncy Ball Challenge

Each group will soon have a small bouncy ball (to be acquired later!). Your group's task is **to create a scientific model that will allow you to predict the rebound height of the ball when you are given a drop height**.

Manager: For the following question (B#1), a*sk your group members for their ideas. Always encourage many different ideas (this is important).*
Speaker: *Ask your group about their ideas for each question. You need to be able to confidently explain them to the class. At any time during a lesson, you should be ready to present your group's ideas to the class.*
Motivator*: Provide encouragement and praise for your group: use humour, keep them energized, and keep on doing this!*

1. **Design.** To create your model, you need to collect data that will help you predict the ball's rebound height if you are given any drop height. Draw a simple sketch that shows how you will collect your data. Include a few short explanations.

2. **Record.** On a whiteboard, record <u>one</u> idea that might help make your measurements and data more reliable.

Recorder: *Place the whiteboard flat on your table so everyone can see it. Record on the white board* ***only*** *what your other group members say. Write* ***large*** *so that students far away in the classroom can read it. Be* ***brief:*** *write just a few words. Use different colours where appropriate.*

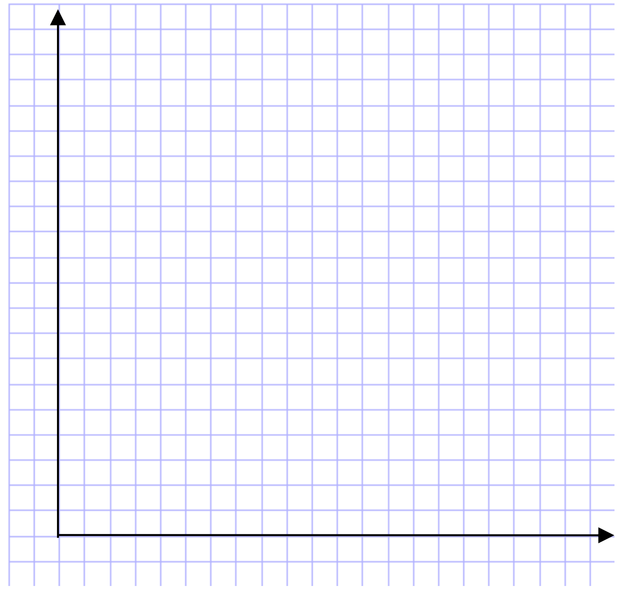
3. **Observe**. Gather the materials you will need and conduct your experiment. Label and record your results here. Make sure a person reading your results below would understand the information.

Recorder: *Check that everyone recorded the data above using labels and the appropriate units.*

In an experiment, we carefully change one quantity to see how it affects another. The quantity that we carefully change is the *independent variable.* The quantity we want to explore as a result of the changes is the *dependent variable.* Typically**,** we record the dependent variable on the vertical axis of a graph.

4. **Represent.** To help analyze the data, represent it graphically on the grid on the next page. Which quantity should be on which axis? Explain.

Scientists look for patterns in data. Does the data in your graph suggest a straight-line pattern or a smooth, curving pattern? Draw an appropriate line or curve. **Never connect the dots! That does not highlight any underlying pattern.**



5. **Analyze**. Draw a line of best fit for your data. Find the slope of your line. Show your calculation below. Record the final result on your whiteboard (don't show the math).

Recorder: *Check your group members' slope calculations.* ***Every time*** *a number is written it must have a unit, e.g.* 15 cm

6. **Interpret.** We need to decide what the slope result **means**. It is not just a number, it tells us something useful about the ball. What would be physically different about a bouncy ball that had a larger slope result? What about a smaller result? Give this quantity a name that helps us understand what it tells us about the ball. Record this name on your whiteboard.

7. **Predict.** You have created a scientific model that describes the ball's bouncy properties! Congratulations! Bring your graph to your teacher and ask for a drop height. Use the slope value from your model to predict a rebound height for your ball. Show your work here.

8. **Test.** Ask your teacher to observe the test of your prediction. A good test result should agree with your prediction to within ± 5 cm. Was your model successful? If not, what could you improve about it?

Manager: *Lead the group through the last question. Focus the group's attention on one role at a time. Encourage many ideas.*
Speaker: *Ask your group questions to help clarify the group's ideas. Imagine what questions a curious student from a non-physics class might ask about these roles. Be prepared to speak to the class about any of them.*

9. **Summarize.** In the chart below, summarize the responsibilities of each role in the group.

Manager	Recorder	Speaker

Recorder: *Clean off the whiteboard at the end of class.*

SPH3U: Homework – How Groups Work Name:

On the course website are two videos which chronicle the exploits of a dysfunction physics group and a well-functioning physics group. Begin by viewing the video of the dysfunctional group (https://youtu.be/vgF_lmPqbOA).

A: Dysfunctional Group

1. **Observe.** Watch the video and note in the chart below any actions or behaviours of Sam, Robert or Mike that contribute to the poor functioning of the group.

Sam	Robert	Mike

2. **Reflect**. The video is something of an exaggeration, but it does help us to think about our own behaviours. Which individual(s) do you think you share the most habits with? (Of course you won't be as extreme as these guys, but maybe you have a tendency to do some of the same things? Be honest!) Explain.

3. **Reason.** Imagine you were a well-function member of this group. Describe some actions you would have taken to help the group work better (i.e. to help smooth over some of the problems you mentioned above).

B: The Well-Functioning Group

1. **Observe.** Watch the video of the functional group (https://youtu.be/xAJKxNUbjf8). Record in the chart below the positive behaviors of Sam, Robert and Mike which help the group to function well.

Sam	Robert	Mike

2. **Reflect.** Which of the behaviours that you mentioned in the previous question do you think you share with Sam, Robert or Mike? Explain.

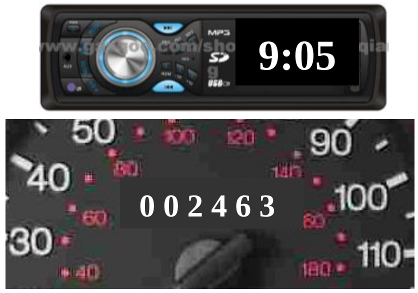
3. **Reflect.** Which of the behaviours that you noted in question B#1 would you like to encourage more of in yourself? How can you do this?

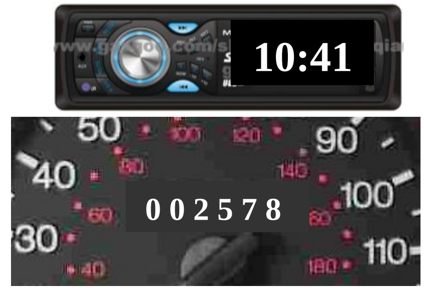
4. **Evaluate.** Use the chart on the right to evaluate the quality of the work you have done on this page. 5 = excellent, 1 = poor

Quality Work Criteria	Mark
My responses use thoughtful, complete sentences and are very easy to read.	
I took time and care with all parts.	

SPH3U: Measurement and Numbers Homework Name:

You decide to take a trip to with a friend to watch a concert. When you begin driving, you glance at the clock in your car and at the car's odometer, which measures how far the car has traveled in kilometres. As you pull in to the concert parking lot, you look at the clock and the odometer a second time.





1. **Reason.** What is the instrumental uncertainty of the clock and the odometer?

2. **Record.** How much time did the trip take in **minutes**? How far did you travel? Record the results using measurement notation.

3. **Estimate.** What was your speed during this car ride? (don't use your calculator!) Don't change any units: use units of kilometers per minute.

4. **Calculate.** Find your speed. Carefully go through the explanation process for calculations and cross out each sub-heading that is listed for you as you complete that part. (For example: ~~Describe purpose~~)

Explanation process

Describe purpose, complete equations, substitutions with units, calculate result, final statement

5. **Interpret.** Explain what the speed result means. For example, how far does this result suggest you are traveling during every minute of the trip?

6. **Evaluate.** Do you think your interpretation of the speed result is 100% correct? Why?

7. **Evaluate.**
   (a) Use the chart to the right to help evaluate the quality of your work. Give each criteria a mark out of five (5 = excellent, 1 = missing or poorly done)
   (b) Based on your evaluation, use a different colour to make improvements to your work.

Quality Work Criteria	Mark
My responses use thoughtful, complete sentences and are very easy to read.	
I carefully showed and crossed out all steps in the explanation process (Q#4).	
I wrote numbers with units and an appropriate number of significant digits.	
I took time and care with all parts.	
This work would be useful for **any** student to study from in the future.	

SPH3U: How to Answer a Question?

Recorder: ___________________	
Manager: ___________________	
Speaker: ___________________	
0 1 2 3 4 5	

Manager: After everyone signs up for group roles today, ask them to go back to yesterday's summary of your responsibilities and review them.

Manager: Ask you group how they would like to go through the new information below. The group can choose to have the speaker read it out loud, or everyone can read it silently.

A major focus of Gr. 11 physics is the careful explanation of our observations and ideas. Every question you encounter should be carefully explained using complete sentences and correct English. Even if the question doesn't actually say "explain", you must still justify your answers and outline your reasoning.

High quality responses to any physics question must be **correct**, **clear**, **concise** and **complete**. We will routinely use these terms and the notation explained below for the evaluation of your daily written work.

Criteria	Description	Notation
Correct	The physics is correctly stated. Conclusions follow logically from the stated evidence and refer to key definitions or laws. Technical details are all present and correct.	Incorrect sections are underlined and given an "__X__". Correct ideas are checked " √ "
Clear	The explanation is precisely stated with a good choice of physics vocabulary. The explanation is straight forward with no awkward or unclear phrases. Spelling and grammar are correct.	Unclear sections are underlined with a wiggly line and ~~~~~ given a "?" A poor word choice is indicated by a wiggly line. Spelling errors are cirlced.
Concise	There are no extraneous or distracting statements which may or may not be correct.	Phrases that are not relevant are crossed out. ~~Like this~~.
Complete	No important parts of the explanation are missing. The evidence supporting the conclusion is mentioned along with the relevant definitions or laws.	Where an explanation is missing or incomplete we will write ". . . ." or "and …" or "more …" or give a clear hint at what is missing: "force?"

Your daily work in physics will be marked based on the four C's criteria for high quality responses. An overall mark will be assigned on a scale of 0 to 5 depending on how your responses meet the four criteria according to the rubric below.

0-2 "Poor"	3 "OK"	4 "Good"	5 "Awesome!"
Responses are missing important parts, fundamentally incorrect, or challenging to understand. A "yes or no" answer is given.	Response is basically correct, but contains problems or omissions.	Response is correct. Only minor details could be improved or clarified.	Response is thoughtful, clear and complete. If another physics teacher saw it they would say, "Wow! A grade 11 student wrote this?"

A: Mark Up These Responses!

1. **Evaluate.** Below you will find five student responses to question B#6 from yesterday's activity.
   (a) Mark up each response according to the four C's criteria **using the notation shown above**.
   (b) Use this rubric below each response to evaluate it after you have marked it up. **Circle** any key words in the rubric's description to highlight you rationale and then circle the mark on the rubric.

> **6. Interpret.** We need to decide what the slope result **means**. It is not just a number; it tells us something useful about the ball. What would be different about a bouncy ball that had a larger result? What about a smaller result? Give this quantity a name that helps us understand what it tells us about the ball. Record this name on your whiteboard.

Response1: **It means the bounciness of the ball.**

0-2	3	4	5
Responses are missing important parts, fundamentally incorrect, or challenging to understand. A "yes or no" answer is given.	Response is basically correct, but contains problems or omissions.	Response is correct. Only minor details could be improved or clarified.	Response is thoughtful, clear and complete. If another physics teacher saw it they would say, "Wow! A grade 11 student wrote this?"

<u>Response 2</u>: The interperetation of the slope of the line helps us to know how it bounces. Bigger slops means a bigger bounce. Smaller slops is less bounce.

Response 2

0-2	3	4	5
Responses are missing important parts, fundamentally incorrect, or challenging to understand. A "yes or no" answer is given.	Response is basically correct, but contains problems or omissions.	Response is correct. Only minor details could be improved or clarified.	Response is thoughtful, clear and complete. If another physics teacher saw it they would say, "Wow! A grade 11 student wrote this?"

<u>Response 3</u>: We can interpret the slope of the line to mean the "bounciness" of the ball, which compares the bounce height with the drop height. It is the bounciness of the ball depending on the drop height. A bigger value is bouncier, a smaller is less.

Response 3

0-2	3	4	5
Responses are missing important parts, fundamentally incorrect, or challenging to understand. A "yes or no" answer is given.	Response is basically correct, but contains problems or omissions.	Response is correct. Only minor details could be improved or clarified.	Response is thoughtful, clear and complete. If another physics teacher saw it they would say, "Wow! A grade 11 student wrote this?"

<u>Response 4</u>: Slope is the rebound. A larger slope value means the ball will bounce back closer to its drop height. A smaller slope value means it will bounce back to less of its drop height.

Response 4

0-2	3	4	5
Responses are missing important parts, fundamentally incorrect, or challenging to understand. A "yes or no" answer is given.	Response is basically correct, but contains problems or omissions.	Response is correct. Only minor details could be improved or clarified.	Response is thoughtful, clear and complete. If another physics teacher saw it they would say, "Wow! A grade 11 student wrote this?"

<u>Response 5</u>: **We call it "rebound". It rebounds more when its bigger and it rebounds less when its smaller. It helps us to know how much rebound the ball has.**

Response 5

0-2	3	4	5
Responses are missing important parts, fundamentally incorrect, or challenging to understand. A "yes or no" answer is given.	Response is basically correct, but contains problems or omissions.	Response is correct. Only minor details could be improved or clarified.	Response is thoughtful, clear and complete. If another physics teacher saw it they would say, "Wow! A grade 11 student wrote this?"

2. **Reason.** You may have noticed that none of the responses earned a 5. Use the best ideas from the different student examples to create a 5/5 response based on the 4 C's. Call your teacher over to check your awesome response.

SPH3U Homework: Learning About Your Brain! Name:

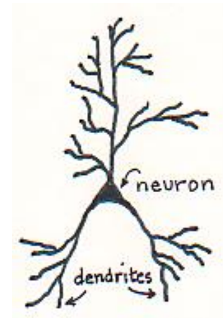
How Your Brain Learns and Remembers

Minneapolis Community & Technical College

Part 1: What Happens Inside Your Brain When You Learn Something New?

Meet Your Brain

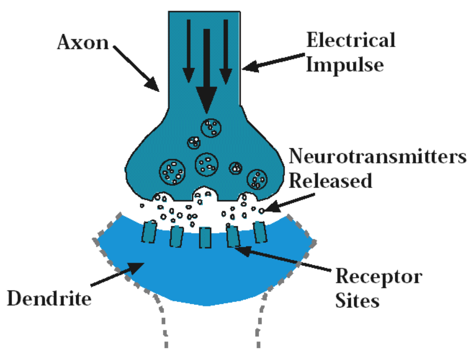
Brain cells are called neurons. You are born with at least 100 billion neurons. Dendrites (fibers) grow out of the neurons when you listen to/write about/talk about/ practice something. Learning is natural. Neurons know how to grow dendrites, just like a stomach knows how to digest food. Learning is growth of dendrites. New dendrites take time to grow; it takes a lot of practice for them to grow.

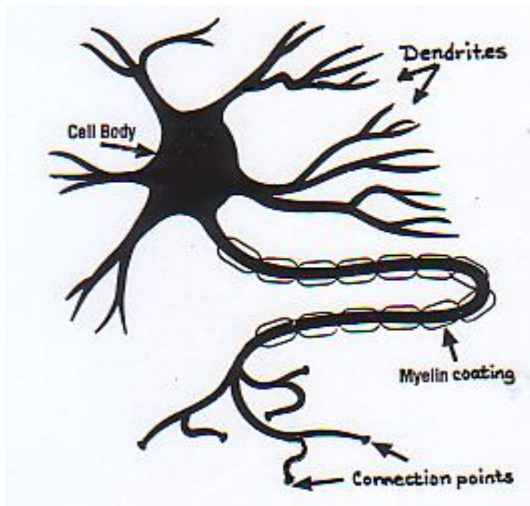


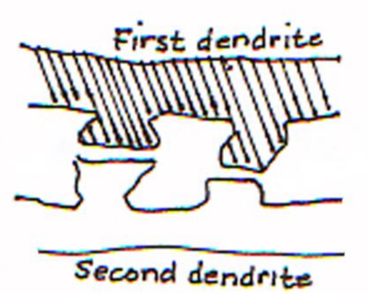
Connections Form between Neurons

When two dendrites grow close together, a contact point is formed. A small gap at the contact point is called the synapse. Messages are sent from one neuron to another as electrical signals travel across the synapse.

Synapse







Practice Improves Connections

Special chemicals called neurotransmitters carry the electrical signals across the synapse. When you practice something, it gets easier for the signals to cross the synapse. That's because the contact area becomes wider and more neuro-transmitters are stored there. When you practice something, the dendrites grow thicker with a fatty coating of myelin. The thicker the dendrites, the faster the signals travel. The myelin coating also reduces interference. With enough practice, the dendrites build a double connection. Faster, stronger, double connections last a very long time. You remember what you learned!

Short-term memory is VERY short!

If you learn something new and do it only once or twice, the dendrite connection is very fragile and can disappear within hours. Within 20 minutes, you remember only 60%. Within 24 hours, you remember only 30%. But if you practice within 24 hours, and then practice again later, you remember 80%.

Make the Most of Practice Time…

You grow dendrites for exactly the same thing you are practicing. If you listen or watch while math problems are solved, you grow dendrites for listening or for watching. If you read over your notes, you build dendrites for reading. If you actually solve the problems yourself, you grow dendrites for solving.

Part 2: Brain Friendly Ways to Learn Better

A: Grow Your Intelligence

You can grow your intelligence, because your brain knows how to grow dendrites just like your stomach knows how to digest food. Think about a baby who learns to speak in its native language without any special classes or training!

B: Do Something Active to Learn

You must do something active to learn, like explaining, solving, drawing, or writing. That's because dendrites grow ONLY when you are actively doing something. No one else can grow dendrites for you!

C: Grow Off of What You Know

Dendrites cannot grow in a void. New dendrites can only grow off of what is already there. New skills must connect to, and grow off of, previously learned skills. If you do not have the necessary dendrites in place, new material will seem to go "right over your head".

D: Give It Time and Practice

Learning takes time, because it takes a lot of practice for dendrites to grow. This is why you do homework. This is why trying to cram everything into your brain the night before a test doesn't work.

E: Mistakes Are Essential

Making mistakes, and getting feedback so you can correct them, allows you to check the accuracy of the connections in your brain. Be sure to get feedback quickly so you don't practice the wrong thing and build a strong, but wrong, connection!

F: Emotions Affect Learning and Memory

Anxiety floods your body with adrenaline ("fight or flight").Adrenaline makes it hard for the neurotransmitters to carry messages across the synapses in your brain. That causes "blanking out" on a test.

G: How can emotions help you?

Endorphins make you feel calm. Your body produces endorphins when you relax, exercise, laugh, or learn new things. If you practice producing calming hormones, it will help when you are under stress.

Part 3: What Does All This Mean For Me?

Use your understanding from this article to answer the following questions. (Remember to give a 5/5 response!)

1. **Explain.** Marie says, "I listen carefully in class and everything makes sense. But when I get home and start on the homework, I am lost. What's going on?" Explain to Marie why.

2. **Explain.** Isaac says, "I attend class, do all the homework, and feel like I understand everything. Then why do I just 'blank out' on the test and can't do anything?" Help Isaac understand why.

3. **Explain.** Emmy says, "Why should I show all the steps in this homework? It's so much extra work." Respond to Emmy.

4. **Explain.** Albert says, "I've haven't done homework for a week and there's a test tomorrow, but I'll be fine if I do it all tonight." Explain why Albert is in trouble.

5. **Evaluate.** In class you learned how your written work in physics will be marked and evaluated. Use the rubric below to evaluate your responses to the homework questions above. **Circle** the mark on the rubric below and circle any key words in the rubric's description to highlight your rationale.

0-2 "Poor"	3 "OK"	4 "Good"	5 "Awesome!"
Responses are missing important parts, fundamentally incorrect, or challenging to understand. A "yes or no" answer is given.	Response is basically correct, but contains problems or omissions.	Response is correct. Only minor details could be improved or clarified.	Response is thoughtful, clear and complete. If another physics teacher saw it they would say, "Wow! A grade 11 student wrote this?"

SPH3U: Measurement and Numbers

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

Measurements are the backbone of all science. All scientific ideas and models, no matter how slick, are only as good as the measurements that support them. Without careful measurements, science is mostly guess work and hunches – suspicions and rumours!

A: The Meter Stick

Our most basic scientific tool is the meter stick. But, do you know how to use it? Please get one meter stick for your group.

1. **Describe.** Examine the markings on the meter stick. What is the size of the smallest interval **marked** on it? What fraction of a metre is this interval?

Estimating is a strategy to quickly come up with a value or result **without** doing a careful measurement or calculation. We can estimate a measurement by "eyeballing" the situation, imagining using the measuring tool, reflecting on your personal experiences, or making a skilled guess. We understand that an estimated result is not quite right, but is hopefully close enough that it helps us to think about the situation.

2. **Estimate** (*individually).* Without using the meter stick, estimate the height of your desk in units of centimetres. Do this quickly and don't worry about being "right".

3. **Measure** (*as a group).* Use the metre stick to carefully measure the height of your desk. If you can estimate a number between the smallest intervals marked on the meter stick, do so.

Significant digits are the digits in a number or measurement that are reliable or trustworthy. You would be pretty confident that the value of a significant digit was very close to the *actual value*. The *instrumental uncertainty* of a measuring device is the smallest interval **you** personally can distinguish from the device. The instrumental uncertainty gives a rough guide for deciding on the last significant digit in a measurement.

4. **Explain.** Emmy used a regular metre stick to measure the height of her desk. She says to her group, "My measurement is 75.35 cm, which has three significant digits and an uncertainty of 0.1 cm." Do you agree with Marie? Explain.

The number we read from a measurement device is the *indicated value*. When you record a measurement, **always** record it with the indicated value, the instrumental uncertainty, and a unit like this: "75.3 ± 0.1 cm". This notation means that we think the actual value is somewhere between 75.4 cm and 75.2 cm. We will call this *measurement notation*. All measurements should be recorded this way, even if we don't remind you!

5. **Interpret.** Write your height measurement using measurement notation. What range of values does your notation mean?

B: The Stopwatch

Now we will examine another common measuring device. You will need a stop watch (you can use a smartphone if you like).

1. **Reason.** Albert measures the time for Marie to walk across the classroom. His timer reads 00:07.81. The "7" in this display reading means "7 seconds". Explain what each digit in this display reading means. (This is a review of place values for the decimal system!)

2. **Record.** Measure the time for one group member to walk the length or width of the classroom. What is the instrumental uncertainty of your stopwatch? Write the result from your stopwatch as a decimal number using measurement notation.

C: Calculating a Result

1. **Estimate** (*individually*)**.** How far did your group member travel during the time interval you measured? Don't share your estimations.

2. **Measure.** Use a long measuring tape to measure the distance. Use measurement notation.

Recorder: *always check that your group continues measurement notation from today onwards!*

The *speed* of an object is the distance it travels in each unit of time: *speed* = *distance* / *time interval*. To *estimate a calculation*, change the values to simple numbers and make a quick mental calculation. Don't write down any work. Simple numbers are ones that add, subtract, multiply, or divide easily. For example, a speed calculation: 71 m ÷ 32 s = 2.219 m/s becomes 80 m ÷ 40 s = 2 m/s

3. **Estimate.** What is the speed of your group member? Don't use a calculator!

4. **Calculate.** When we perform calculations in science we always carefully explain our process. Complete any missing parts of the following steps using your group's measurements.

Explanation Process for Calculations	Student Work
(1) Describe the purpose of the math you are going to do.	*Find the walking speed of my group member.*
(2) Write the complete equation using symbols (or words).	$speed = \frac{distance}{time\ interval}$
(3) Substitute the values. **Always** include a unit with each number. Do not use measurement notation during calculations!	$speed = \frac{\quad}{\quad}$
(4) Calculate a result. Write the result with four significant digits. No measurement notation!	*speed* =
(5) Write a final statement that interprets your calculated result. Use three significant digits. No "±" needed!	*Our group member …*

Guidelines for Writing Numbers	
Measured numbers	• use the instrumental uncertainty to determine the last significant digit, write using measurement notation: 3.752 m ± 0.001 m • write "round" numbers according to the uncertainty: e.g. 2.000 m if the uncertainty is 0.001 m
Calculated numbers or Numbers from problems	• for <u>final statements</u>, use three significant digits to avoid too much rounding error • for <u>calculations</u>, keep an extra (a fourth) digit as a *guard digit* to help reduce the amount of rounding error. • use scientific notation **only** when it is convenient (for really small or really big) numbers • write "round" numbers in a simple way: 2 instead of 2.0 or 2.00
Estimated numbers	• estimations are always very rough results. Only use **one** significant digit.
These are very **rough** guidelines. In grade 12 we will improve on these and in university you will learn the real rules!	

Guidelines for Significant Digits	
Numbers greater than one	• Count three or four significant digits starting with the leftmost digit For example, your calculator reads: 1 056 428, you write: 1 060 000 m or 1.06×10^6 m For example, your calculator reads: 1.001 356, you write: 1 kg or 1.00 kg
Numbers less than one	• Count three or four significant digits starting with the first non-zero digit right of the decimal point For example, your calculator reads: 0.01075, you write: 0.0108 s or 1.08×10^{-2} s

5. **Apply.** After completing a variety of calculations, your calculator displays the following results. Write the result in an appropriate way for a <u>final statement</u>. Use our new guidelines!

1.438947 m/s →	0.127485 m →	5 938 454 km →
5.00001 s →	9.46379 days →	0.000383 s →

SPH3U: Introduction to Motion

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Welcome to the study of physics! As young scientists you will be making measurements and observations, building theories, and testing models that help us to describe how our world works.

A: The Gold Medal Race

A sixteen year-old swimmer from Toronto, Penny Oleksiak, won a gold medal in the women's 100-m freestyle swimming competition at the 2016 Rio Summer Olympics. Your teacher will show you the video of this exciting race. A team of sports scientists and coaches have helped Penny reach this extraordinary level of performance. And since Penny was only 16 years old when she won, they expect her to get even better! You are now a sports scientist and your job is to analyze Penny's race performance and help her improve. Thanks to Ryan Atkison from the Canadian Sports Institute, Ontario for the data from Penny Oleksiak's race.

1. **Explain.** Watch the video of her gold-medal winning race. After watching, Isaac says, "I want to make some distance and time measurements for her motion, but I don't know how. Her arms are moving, her legs are moving … it all seems very complicated!" Albert says, "I have an idea to simplify things. Let's assume Penny is just a blob moving through the water. No arms, no legs." In what ways is Albert's idea crazy? In what ways is it reasonable and helpful?

Our world is too complex for any one person to understand everything: there is just too much going on! To deal with this, scientists make *models* that are simplified scientific pictures of a part of our complex world. Every model is built out of assumptions. A *system* is an object or group of objects that we want to study. An *assumption* is a statement about the system that is not quite 100% correct, but is probably pretty close. A *reliable* assumption is one that helps us create a model that will make predictions about the system that closely match our measurements.

It is often helpful to use the *point particle assumption* when we create a scientific model. With this assumption, we model the system as a small blob of matter. This is a reliable assumption if the details of the object's size or its shape don't have a noticeable effect on the predictions of the model.

2. **Describe.** Watch the video again. We will break up the race into different intervals where she is swimming or moving differently. Describe how she swims or moves differently during each interval of the race.

Interval	Description
(1) Underwater	
(2) Front Crawl	
(3) Turn Around	
(4) Front Crawl	

A scientific model is more reliable (it will give better predictions) when it focuses on a specific interval of time.

3. **Reason.** During which interval of the race would it be easiest to make distance, time, or speed measurements? Why?

4. **Reason.** As a sport scientist, you want to focus your attention on the longest interval of Penny's race. You are concerned that she might be speeding up or slowing down too much during this interval. Why are you concerned?

5. **Reason.** How could you use distance and time measurements to verify whether Penny is moving at steady rate?

6. **Define.** *(as a class)* We need a definition that will allow us to test whether Penny, or any other object, moves with a constant speed.

Definition: Constant Speed

7. **Explain.** Below are two sets of data from two different swimming races. Use our new definition to *explain* which set is an example of constant speed. (One of these is from Penny's race!)

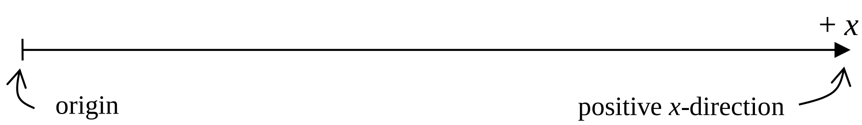
Position in Pool	15 m	25 m	35 m	45 m
Time	6.52 s	11.83 s	17.10 s	22.69 s

Position in Pool	15 m	25 m	35 m	45 m
Time	6.52 s	11.83 s	17.14 s	22.45 s

B: Testing a Claim – Constant Speed

It's time to test your understanding and an advertising claim. A motorized car, which we affectionately call the physics buggy, is sold with this description: "Equally appealing to students of all ages, this simple but powerful toy provides a visible source of uniform speed." Your task is to design an experiment that will test the claim that the toy moves with a *constant* speed.

To describe the *position* of an object along a line we need to know the distance of the object from a reference point, or origin, on that line and what direction it is in. One direction along the line is chosen to be the positive *x*-direction and the other negative. This choice is the *sign convention*. Choose your sign convention such that the position measurements you make today will be positive.



1. **Plan.** Your group will use one physics buggy, a large measuring tape (share if necessary) and a stopwatch (or your smartphone with lap timer!).
   (a) Describe a simple experiment using **position** and **time** measurements that will allow you to decide whether the buggy moves with a constant speed.
   (b) Draw a simple picture of the experiment, including the origin, and illustrate the quantities you will measure.

*** *Check your plan with your teacher****

2. **Measure.** Find your equipment and conduct your experiment. Record your data below. Record your buggy number:__________. Note: we would like to use the time values for the buggy to travel from the **origin** to each position.

Position, x (m)								
Time, t (s)								

3. **Reason.** When you made your position measurements, what do you think **your** instrumental uncertainty was? What about your time measurements? Write down one sample measurement for each using measurement notation.

4. **Reason.** Is the speed of your buggy constant? Describe how you can decide just by looking at the measurements in your chart (remember that there are uncertainties!).

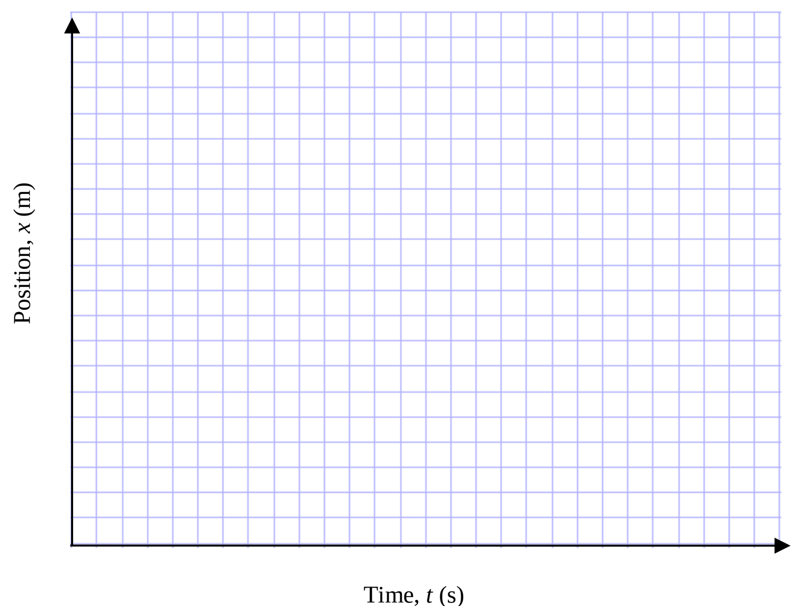
A *motion diagram* is a sequence of dots that represents the motion of an object. Imagine that the object produces dots while it moves after equal intervals of time. We draw these dots along an axis that shows the positive direction and use a small vertical line to indicate the origin. The scale of your diagram is not important, as long as it shows the right ideas.

5. **Interpret.** Below is a motion diagram for one student's buggy. Explain how you can tell whether the speed of this buggy was constant.

Graphing. Choose a convenient scale for your physics graphs that uses most of the graph area. The scale should increase by simple increments. Label each axis with a name, symbol and units.

Line of Best-Fit. The purpose of a line of best fit is to highlight a pattern that we believe exists in the data. Real data always contains uncertainties that lead to *scatter* (wiggle) amongst the data points. A best-fit line helps to average out this scatter and uncertainty. Any useful calculations made from a graph should be based on the best-fit line and **not** on the data chart or individual data points. As a result, we **never** connect the dots in our graphs of data.

6. **Represent.** We want to look for patterns in the position of the buggy. Plot your data on a graph with position on the vertical axis.



7. **Find a pattern.** To create a model of the motion of the buggy, we need to look for a pattern in the data. Do you believe your data is best modelled by a curving pattern or a straight-line pattern? How well does your data fit a straight-line pattern?

8. **Reason.** Imagine an experiment with a second buggy that produces a similar graph, but with a steeper line of best fit. What is different about the movement of the second buggy? Explain.

9. **Represent and Calculate.** You are familiar with the expression for slope from your math class. Replace the math class symbols with physics symbols from this graph. For example, on this graph there are no "*y*" symbols, the *x*-axis position is on the vertical axis instead. Use the physics symbol "*v*" to replace the math symbol "*m*". Next, substitute the values from the graph including their units. Compute the final result.

math class expression: $m = \frac{y_2 - y_1}{x_2 - x_1}$ physics graph expression:

10. **Interpret.** What does the slope of your line tells us about the motion of the buggy? For example, what does the buggy do every second?

> The slope of a position graph gives the object's *velocity*. In the study of physics, velocity has a very special meaning that makes it different from speed.

11. **Evaluate.** Based on your experimental results how well do the advertised claims for the buggy hold up?

12. **Predict and Test.** Use your model (the slope result) to predict how much time it will take your buggy to travel 2.15 m. Follow the explanation process below to show your work.

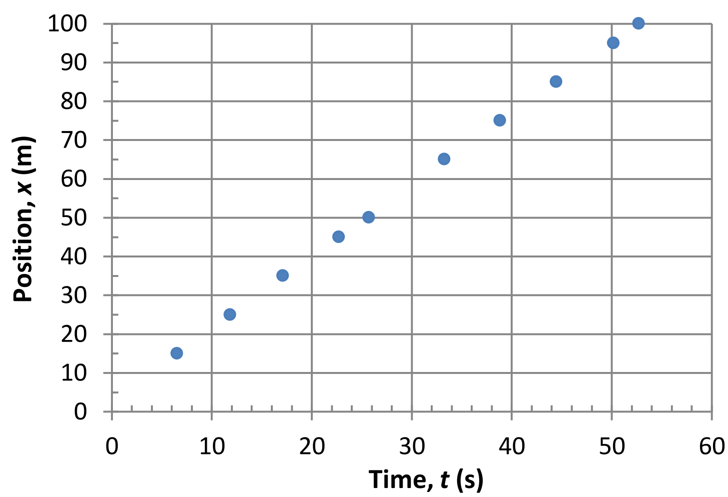
Explanation Process for Calculations	**Your Work**
(1) Describe the purpose of the math you are going to do.	
(2) Write the complete equation using symbols (or words).	
(3) Substitute the values. Always include a unit with each number. Do not use measurement notation for calculations.	
(4) Calculate a result. Write the result with four significant digits.	
(5) Write a final statement that interprets your calculated result. Use three significant digits.	

*** *Set up your buggy and call your teacher over to test your prediction.****

C: Penny's Gold Medal Race

Now back to our regularly scheduled program. The graph below shows the position and time data for Penny during her gold-medal race. Note that the data begins a short while after the start of the race.

1. **Interpret.** According to the data in the graph, is her speed constant? Explain how you decide.



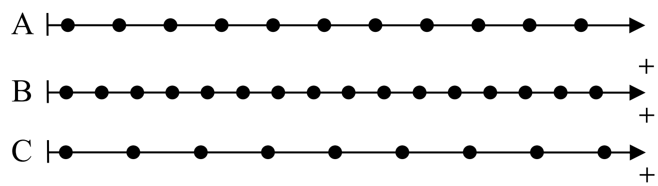
2. **Find a Pattern.** Draw a line of best fit that matches her data. Use physics symbols to construct an expression for the slope of the graph. Use this to calculate her velocity.

3. **Summarize.** In how many different ways was motion represented in this investigation? Explain.

SPH3U Homework: Constant Speed   Name:

1. The image below shows the International Space Station as it travels between the moon and Earth on February 4, 2017, as photographed by astral photographer Thierry Legault. The camera took photos after equal intervals of time. Is the speed of the ISS constant or changing? Explain.

2. Three different physics buggies produce the motion diagrams shown to the right.
   (a) **Reason**. Rank the speed of the three buggies from fastest to slowest. Explain your reasoning.



3. **Reason.** Different student groups collect data tracking the motion of different toy cars. Study the charts of data below. Which charts represent the motion of a car with constant speed? Explain how you can tell.

A		B	
Position (cm)	Time (s)	Position (cm)	Time (s)
0	0	0	0
15	1	2	5
30	2	6	10
45	3	12	15
60	4	20	20

4. Canadian swimmer Penny Oleksiak completed the first 50 m of her gold medal race in a time of 25.7 s.
   (a) **Estimate.** Without using a calculator, estimate her speed during the first 50 m of her race. This time, please show your thinking.

   (b) **Solve.** Find Penny's speed. Carefully go through the explanation process for calculations and cross out each sub-heading when you have completed that part of the process. (For example: ~~Describe purpose~~, ~~complete equations~~, ...)

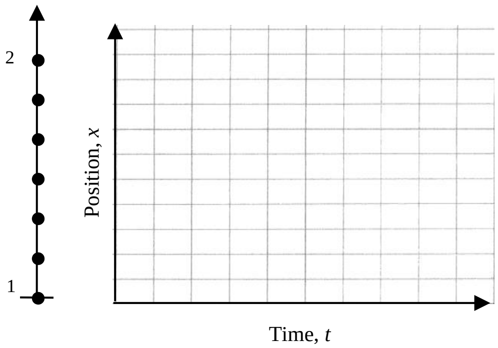
Explanation process

Describe purpose, complete equations, substitutions with units, calculate result, final statement

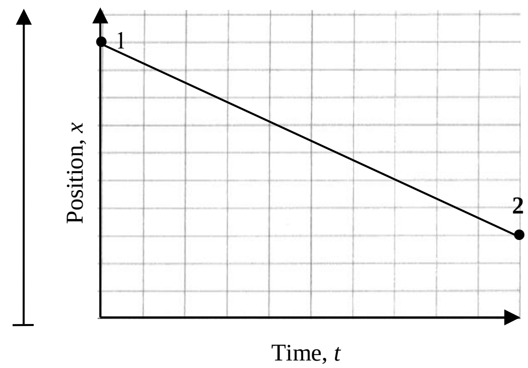
Quality Work Criteria	**Mark /5**
My responses use thoughtful, complete sentences and are very easy to read.	
I carefully showed and crossed out all steps in the explanation process (Q#4).	
I wrote numbers with units and an appropriate number of significant digits.	
I took time and care with all parts.	
This work would be useful for **any** student to study from in the future.	

SPH3U Homework: Position Graphs Name:

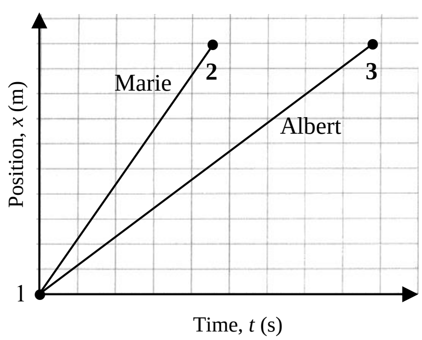
1. Emmy walks along an aisle in our physics classroom. A motion diagram shows her changing position. Two events, her starting position (1) and her final position (2) are labeled. Use the motion diagram sketch the position graph. (A sketch doesn't worry about exact values.)

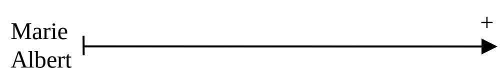


2. Use the position-time graph to construct a motion diagram for Isaac's trip along the hallway from the washroom towards our class. We will set **the classroom door as the origin**. Label the start (1) and end of the trip (2).



3. Albert and Marie both go for a stroll from the classroom to the cafeteria as shown in the position-time graph to the right.
   (a) Draw a motion diagram for both Albert and Marie. Draw the dots for Marie above the line and the dots for Albert below. Label their starting position (1) and their final position (2 or 3). Hint: think about their initial and final positions!





Pretend you are talking to a friend who has **never** seen a position graph before. **Explain** to your friend the answer the following questions.

(b) Who leaves the starting point first?

(c) Who travels faster?

(d) Who reaches the cafeteria first?

Quality Work Criteria	**Mark /5**
My responses use thoughtful, complete sentences and are very easy to read.	
My graphs are carefully sketched and use event numbers	
My motions diagrams are neat and include event numbers	
I took time and care with all parts.	
This work would be useful for **any** student to study from in the future.	

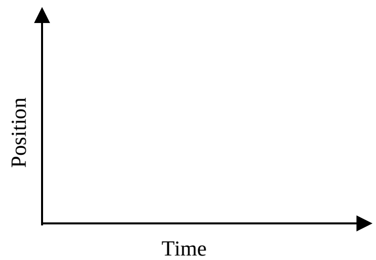
SPH3U: Interpreting Position Graphs

Today you will learn how to draw and interpret position-time graphs.

A: Interpreting Position Graphs

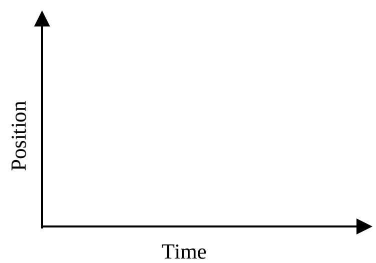
1. **Observe and Interpret** (*as a class*)**.** A student will move in front of the motion detector according to the descriptions below. The origin is at the sensor and the direction away from the sensor is chosen as the positive direction. We will call the line along which the student moves the *x*-axis. After observing each result from the computer, interpret the meaning of the graph.

(a) Standing still, close to the sensor



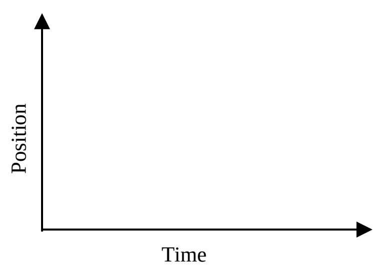
Feature	Value	Meaning
Type of graph		
Starting position		
Size of slope		

(b) Standing still, far from the sensor



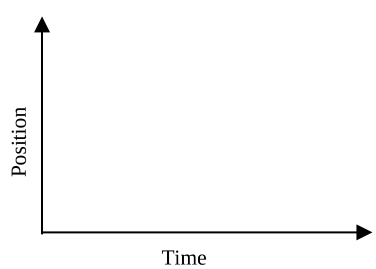
Feature	Value	Meaning
Type of graph		
Starting position		
Size of slope		

(c) Walking slowly away from the sensor at a steady rate.

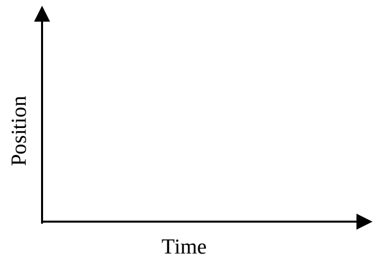


Feature	Value	Meaning
Type of graph		
Starting position		
Shape of graph		
Size of slope		
Sign of slope		

(d) Walking quickly away from the sensor at a steady rate.



Feature	Value	Meaning
Type of graph		
Starting position		
Shape of graph		
Size of slope		
Sign of slope		

<table>
<tr><td rowspan="6">(e) Walking slowly towards the sensor at a steady rate
</td><td colspan="3">Interpret
Feature | Value | Meaning</td></tr>
<tr><td>Type of graph</td><td></td><td></td></tr>
<tr><td>Starting position</td><td></td><td></td></tr>
<tr><td>Shape of graph</td><td></td><td></td></tr>
<tr><td>Size of slope</td><td></td><td></td></tr>
<tr><td>Sign of slope</td><td></td><td></td></tr>
</table>

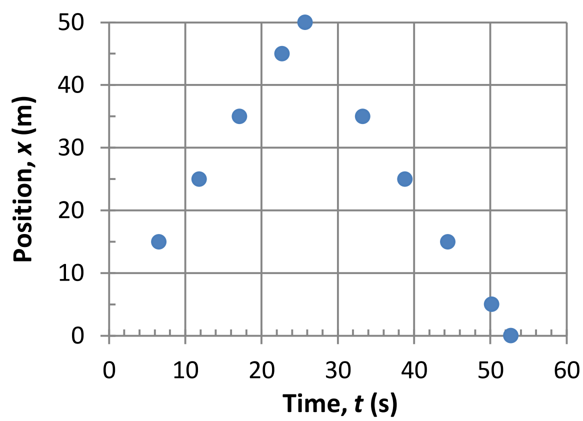
2. **Find a Pattern.** Describe the difference between the position graphs made by walking slowly and quickly.

3. **Find a Pattern.** Describe the difference between the position graphs made by walking towards and away from the sensor.

4. **Interpret.** The position graph from Penny's gold medal race actually looks more like the one to the right (we cheated a bit in the previous lesson – maybe you can figure out why). Identify the two important intervals of time in her race. Interpret the meaning of the position graph for each interval.

   (1):

   (2):

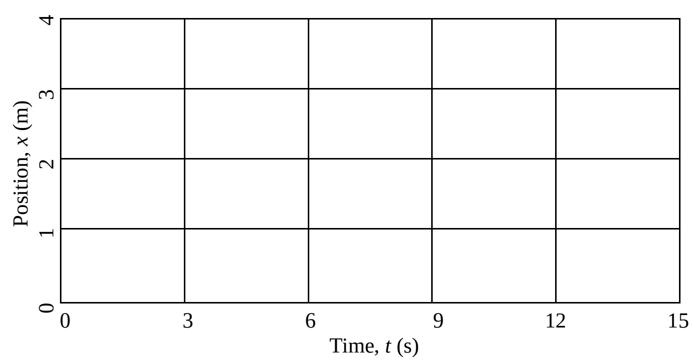


B: The Position Prediction Challenge

Now for a challenge! From the description of a set of motions, can you predict a more complicated graph?

A person starts 1.0 m in front of the sensor and walks away from the sensor slowly and steadily for 6 seconds, stops for 3 seconds, and then walks towards the sensor quickly for 6 seconds.

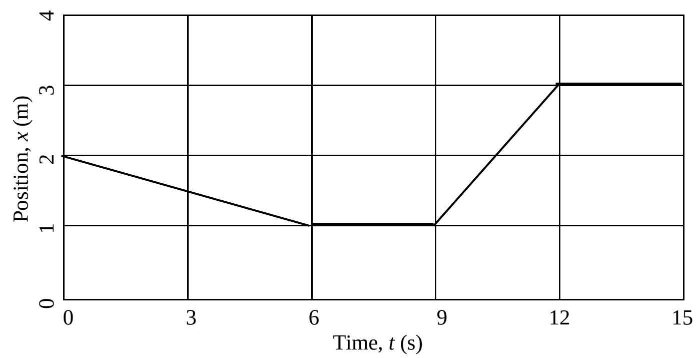
1. **Predict.** (*individually*) Use a dashed line to sketch your prediction for the position-time graph for this set of motions.



2. **Test and Explain.** Use the computer and motion detector to test your predictions. Call out instructions to your group member who is walking. Compare the computer results with your prediction. Explain any important differences between your personal prediction and the computer results.

C: Graph Matching

Now for the reverse! To the right is a position-time graph and your challenge is to determine the set of motions which created it.



1. **Interpret.** (*individually*) Study the graph to the right and write down a list of instructions that describe how to move like the motion in this graph. Use words like *fast, slow, towards, away, steady, and standing still*. If there are any helpful quantities you can determine, include them.

   0-6 seconds:

   6-9 seconds:

   9-12 seconds:

   12-15 seconds:

2. **Test.** (*as a class*) Observe the results from the computer. Explain any important differences between your predictions and the ones which worked for our "walker".

D: Summary

1. Summarize what you have learned about interpreting position-time graphs.

Interpretation of Position-Time Graphs	
Graphical Feature	Physical Meaning
steep slope	
shallow slope	
zero slope	
positive slope	
negative slope	

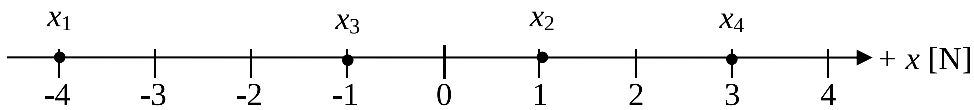
2. What, in addition to the speed, does the slope of a position-time graph tell us about the motion on an object?

We have made a very important observation. The slope of the position-time graph is telling us more than just a number (how fast). We can learn another important property of an object's motion that speed does not tell us. This is such an important idea that we give the slope of a position-time graph a special, technical name – the **velocity** of an object. The velocity is much more than just the speed of an object as we shall see in our next lesson! Aren't you glad you did all that slope work in gr. 9?!

SPH3U Homework: Defining Velocity Name:

Albert walks along York Mills Rd. on his way to school. Four important events take place. The +*x* direction is north.

Event 1: At 8:07 Albert leaves his home.
Event 2: At 8:28 Albert realized he has dropped his phone somewhere along the way and immediately turns around.
Event 3: At 8:43 Albert finds his phone on the ground with its screen cracked (no insurance).
Event 4: At 8:52 Albert arrives at school.



units = kilometers

1. **Represent**. Draw a vector arrow that represents the displacement for each interval of Albert's trip and label them Δx_{12}, Δx_{23}, Δx_{34}.

2. **Calculate.** Complete the chart below to describe the details of his motion in each interval of his trip.

Interval	1-2	2-3	3-4
Displacement expression	$\Delta x_{12} = x_2 - x_1$		
Time interval expression	$\Delta t_{12} = t_2 - t_1$		
Displacement result	$\Delta x_{12} =$		
Direction of movement			
Time interval result	$\Delta t_{12} =$		
Velocity	$v_{12} = \frac{\Delta x_{12}}{\Delta t_{12}} =$		

3. **Reason.** Why do you think the magnitude of his velocity (the number part) is so different in each interval of his trip? What's happening in each?

4. **Explain.** Why is the sign of the velocity different in each interval of his trip?

5. **Calculate.** What is his displacement for the **entire trip**? (Hint: which events are the initial and final events for his whole trip?)

6. **Interpret**. Explain in words what the result of your previous calculation **means**.

Quality Work Criteria	**Mark /5**
My responses use thoughtful, complete sentences and are very easy to read.	
The symbols I use have proper event numbers	
I always include units with every physics quantity I write.	
I took time and care with all parts.	
This work would be useful for **any** student to study from in the future.	

SPH3U: Defining Velocity

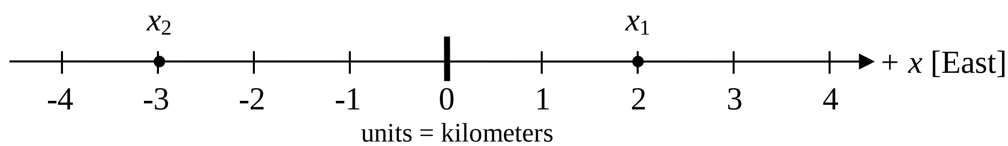
Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

To help us describe motion carefully we have been measuring positions at different moments in time. Now we will put this together and come up with an important new physics idea.

An *event* is something that happens at a certain place and at a certain time. We can locate an event by describing *where* and *when* that event happens. At our level of physics, we will use one quantity, the position (x) to describe where something happens and one quantity time (t) to describe when. Often, there is more than one event that we are interested in so we label the position and time values with an event number (x_2 or t_3).

A: Changes in Position - Displacement

Our trusty friend Emmy is using a smartphone app that records the events during her trip to school. Event 1 is at 8:23 when she leaves her home and event 2 is at 8:47 when she arrives at school. We can track her motion along a straight line that we will call the x-axis, we can note the positions of the two events with the symbols x_1, for the initial position and x_2, for the final position.



1. **Interpret.** What is the position of x_1 and x_2 relative to the origin? Write your answer two ways: mathematically, using a sign convention, and in words describing the direction.

   math: x_1 = 2 m $\qquad$ x_2 =

   words: x_1: 2 metres <u>east</u> of the origin $\qquad$ x_2:

2. **Reason and Interpret.** In what direction did Emmy move? Describe this mathematically and in words. Use a ruler and draw an arrow (just above the axis) from the position x_1 to x_2 to represent this change.

   math: $\qquad$ words:

The change in position of an object is called its *displacement* (Δx) and is found by subtracting the initial position from the final position: $\Delta x = x_f - x_i$. The Greek letter Δ ("delta") means "change in" and always describes a final value minus an initial value. In your work, you will always replace the subscripts "*f*" and "*i*" with the appropriate event number. The displacement can be visually represented by an arrow, called the *displacement vector*, pointing from the initial to the final position. Any quantity in physics that requires a direction to describe it is called a *vector* quantity.

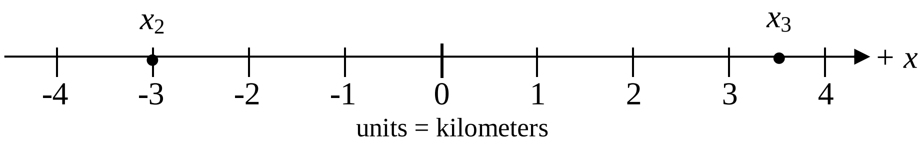
3. **Reason.** Is position a vector quantity? Explain. (Hint: to describe Emmy's position, do we need to mention a direction?)

4. **Reason.** In the example above with Emmy, which event is the "final" event and which event is the "initial"? Which event number should we substitute for the "*f*" and which for the "*i*" in the expression for the displacement ($\Delta x = x_f - x_i$)?

5. **Calculate and Interpret.** Calculate the displacement for Emmy's trip. What is the interpretation of the result? Be sure to mention the number part and the sign of the result. A sample is provided below.

   Sample using different values: $\Delta x = x_2 - x_1$ = 6 km – (-2 km) = 8 km, Emmy moved 8 km to the east of her start

6. **Calculate and Represent.** Emmy continues her trip. Calculate the displacement for the following example. Draw a displacement vector that represents the change in position.



B: Changes in Position and Time

In a previous investigation, we have compared the position of the physics buggy with the amount of time taken. These two quantities can create an important ratio.

When the velocity is constant (constant speed and direction), the *velocity* of an object is the ratio of the displacement between a pair of events and the time interval. In equal intervals of time, the object is displaced by equal amounts.

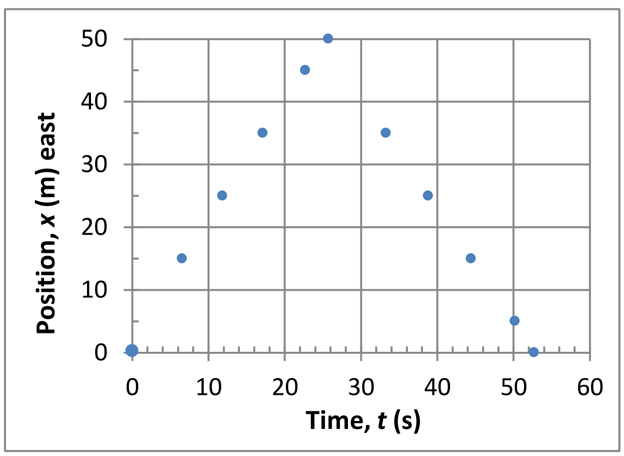
1. **Reason.** Write an algebraic equation for the velocity in terms of v, x, Δx, t and/or Δt. (Note: some of these quantities may not be necessary.)

2. **Calculate.** Consider the example with Emmy between events 1 and 2. What was her displacement? What was the interval of time? Now find her velocity. Provide an interpretation for the result (don't forget the sign!).

In physics, there is an important distinction between *velocity* and *speed*. Velocity includes a direction while speed does not. Velocity can be positive or negative, speed is always positive. For **constant velocity**, the speed is the magnitude (the number part) of the velocity: speed = |velocity|. There is also a similar distinction between *displacement* and *distance*. Displacement includes a direction while distance does not. A displacement can be positive or negative, while distance is always positive. For **constant velocity**, the distance is the magnitude of the displacement: distance = |displacement|.

C: Velocity and Speed

Your last challenge is to find the velocity of Penny from her position-time graph. The positive direction is east. Event 1 is the start of the race, event 2 is when she turns around, and event 3 is when she touches the wall to finish.



1. **Calculate.** What is Penny's displacement during each half of the race? Use the appropriate symbols!

2. **Calculate.** Find her velocity during each half of her race.

3. **Calculate.** Find her speed during each half of the race.

SPH3U: Velocity-Time Graphs

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

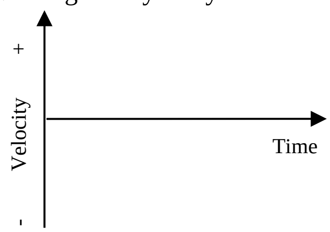
We have had a careful introduction to the idea of velocity. Now it's time to look at its graphical representation.

A: The Velocity-Time Graph

A velocity-time graph uses a sign convention to indicate the direction of motion. We will make some predictions and investigate the results using the motion sensor. Remember that the positive direction is away from the face of the sensor.

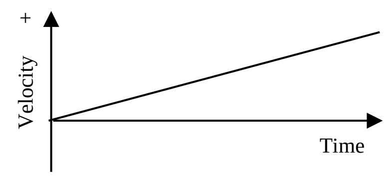
1. **Observe and Interpret.** (*as a class*) A student walks slowly away from the sensor with a constant velocity. Observe a student and record the results from the computer. You may smooth out the jiggly data from the computer.

Walking slowly away from the sensor



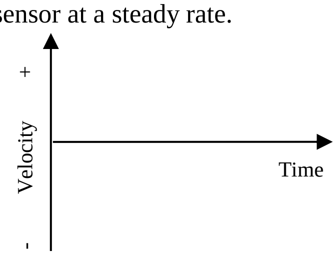
Feature	Value	Meaning
Type of graph		
Sign of velocity values		
Size of velocity values		
Slope of graph		

2. **Explain.** Isaac was asked to predict the shape of the previous velocity graph. He drew the graph to the right. Explain what he was thinking when making this prediction.



3. **Predict.** (*individually*) Sketch your prediction for the four velocity-time graphs that corresponds to each situation described in the chart below and continued on the next page. Use a dashed line for your predictions.

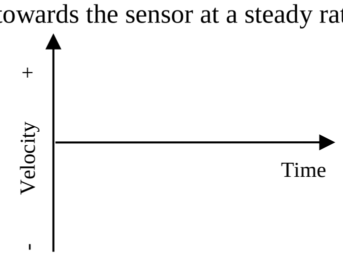
(a) Walking **quickly** away from the sensor at a steady rate.



Interpret

Feature	Value	Meaning
Type of graph		
Sign of velocity values		
Size of velocity values		
Slope of graph		

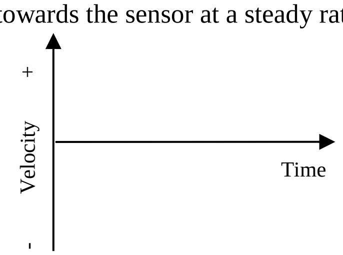
(b) Start 3 m away and walk quickly towards the sensor at a steady rate.



Interpret

Feature	Value	Meaning
Type of graph		
Sign of velocity values		
Size of velocity values		
Slope of graph		

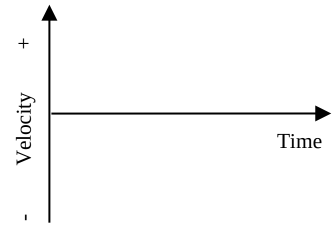
(c) Start 3 m away and walk slowly towards the sensor at a steady rate.



Interpret

Feature	Value	Meaning
Type of graph		
Sign of velocity values		
Size of velocity values		
Slope of graph		

(d) Start 1.5 m away and walk slowly **towards** the sensor at a steady rate.



Interpret

Feature	Value	Meaning
Type of graph		
Sign of velocity values		
Size of velocity values		
Slope of graph		

4. **Observe and Interpret.** (*as a class*) The computer will display its results for each situation. Draw the results with a solid line on the graphs above. Remember that we want to smooth out the bumps and jiggles from the data. Complete the interpretation part of the chart.

5. **Explain.** Based on your observations of the graphs above, how is speed represented on a velocity graph? (How can you tell if the object is moving fast or slow)?

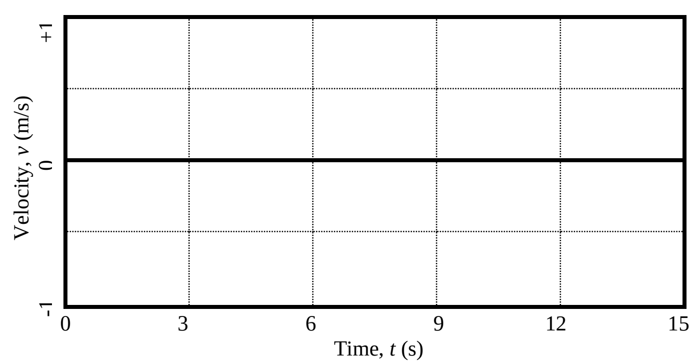
6. **Explain.** Based on your observations of the graphs above, how is direction represented on a velocity graph? (How can you tell if the object is moving in the positive or negative direction)?

7. **Explain.** If everything else is the same, what effect does the starting position have on a velocity graph?

B: The Main Event!

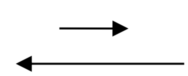
A person moves in front of a sensor. There are four events: (1) The person starts to walk slowly away from the sensor, (2) at 6 seconds the person stops, (3) at 9 seconds the person walks towards the sensor twice as fast as before, (4) at 12 seconds the person stops.

1. **Predict.** (*individually*) Use a dashed line to draw your prediction for the shape of the velocity-time graph for the motion described above. Label the events.



Velocity is a vector quantity since it has a magnitude (number) and direction. All vectors can be represented as arrows. In the case of velocity, the arrow does not show the initial and final positions of the object. Instead it shows the object's speed and direction.

2. **Represent.** Two vector arrows are drawn below representing the velocity of the person in the graph above. One represents her velocity between moments 1 and 2, the other between moments 3 and 4. How can you tell which is which?



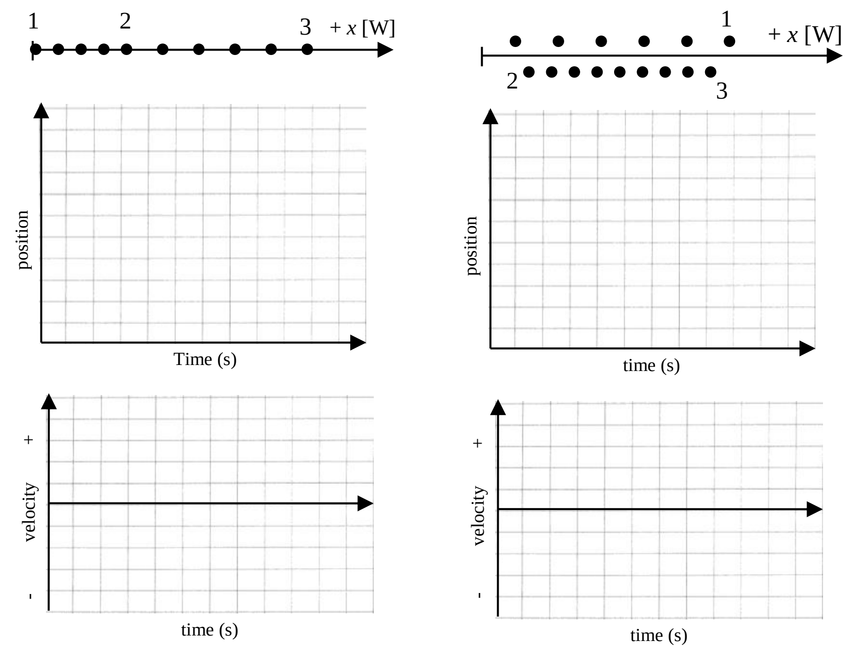
SPH3U Homework: Velocity Graphs Name:

1. Two motion diagrams track the movement of a student walking in a straight line.

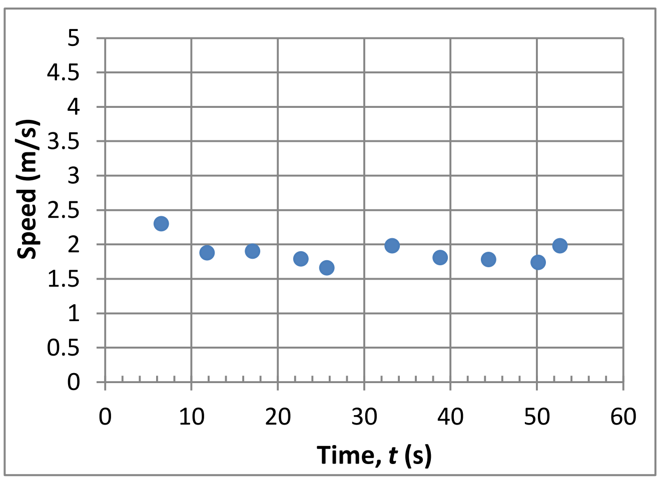
   (a) **Represent.** Sketch a position-time graph for each motion diagram. The scale along the position axis is not important. Use one grid line = 1 second for the time axis.

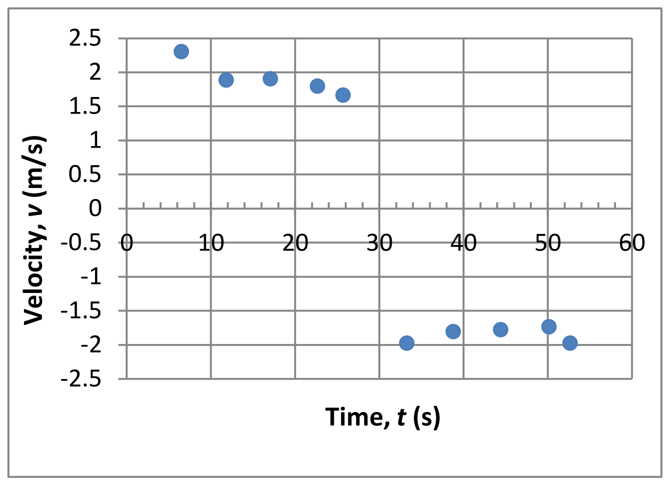
   (b) **Represent.** Sketch a velocity-time graph for each motion diagram. The scale along the velocity axis is not important.

   (c) **Interpret.** Label each section of each representation as "fast" or "slow". Is each set consistent?



2. The two graphs below show data from Penny Oleksiak's 100-m gold-medal race.





   (a) **Read.** What is Penny's speed at 22 s? What is her velocity at 22 s?

   (b) **Read.** What is Penny's speed at 33 s? What is her velocity at 33 s?

   (c) **Interpret.** Is Penny's speed constant? What about her velocity? What is your evidence?

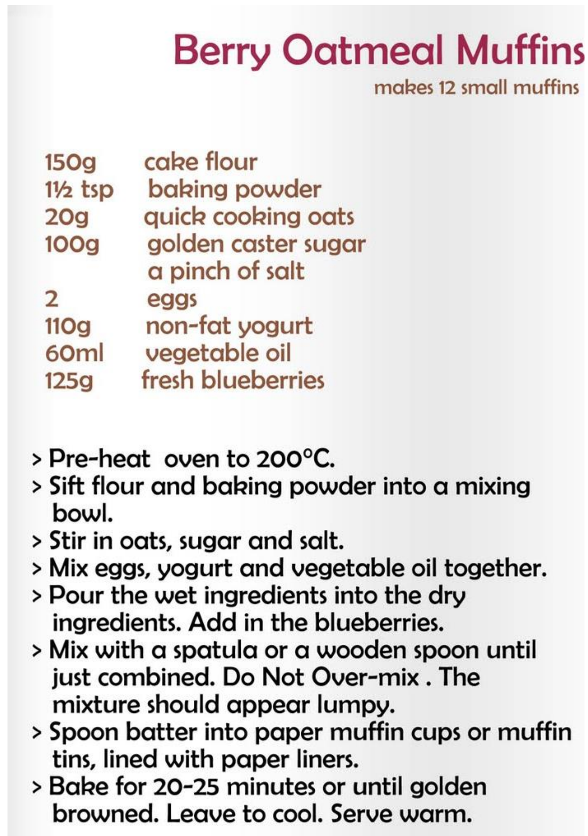
Quality Work Criteria	Mark /5
My responses use thoughtful, complete sentences and are very easy to read.	
I took time and care with all parts.	
This work would be useful for **any** student to study from in the future.	

SPH3U Homework: Conversions

1. You are driving in the United States where the speed limits are marked in strange, foreign units. One sign reads 65 mph which should technically be written as 65 mi/h. You look at the speedometer of your Canadian car which reads 107 km/h. Are you breaking the speed limit? (1 mi = 1.60934 km)

2. You step into an elevator and notice the sign describing the weight limit for the device. What is the typical weight of a person in pounds according to the elevator engineers?

3. You are working on a nice muffin recipe only to discover, halfway through your work, that the quantity of oil is listed in mL. You only have teaspoons and tablespoons to use (1 tsp = 4.92 mL, 1 tbsp = 14.79 mL). Which measure is best to use and how many?



4. Your kitchen scale has broken down just as you were trying to measure the cake flour for your muffin recipe. Now all you have is your measuring cup. You quickly look up that 1 kg of flour has a volume of 8.005 cups. How many cups should you put in your recipe?

5. You convert a time interval from hours into years. Do you expect the number part to be a larger or smaller value? Explain.

Quality Work Criteria	Mark /5
My responses use thoughtful, complete sentences and are very easy to read.	
I assigned a symbol to each quantity I converted.	
I used a conversion ratio in each response.	
I carefully showed how the units divide away in each response.	
This work would be useful for **any** student to study from in the future.	

SPH3U: Conversions

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

In our daily life we often encounter different units that describe the same thing – speed is a good example of this. Imagine we measure a car's speed and our radar gun says "100 km/h" or "62.5 miles per hour". The numbers (100 compared with 62.5) might be different, but the measurements still describe the same amount of some quantity, which in this case, is speed.

A: The Meaning of Conversions

When we say that something is 3 m long, what do we really mean?

1. **Explain.** "3 metres" or "3 m" is a shorthand way of describing a quantity using a mathematical calculation. You may not have thought about this before, but there is a mathematical operation (+, -, ×, ÷) between the "3" and the "m". Which one is it? Explain.

Physics uses a standard set of units, called S. I. (Système internationale) units, which are not always the ones used in day-to-day life. The S. I. units for distance and time are *metres* (*m*) and *seconds* (*s*). It is an important skill to be able to change between commonly used units and S.I. units. (Or you might lose your Mars Climate Orbiter like NASA did! Google it.)

2. **Reason.** Albert measures a weight to be 0.454 kg. He does a conversion calculation and finds a result of 1.00 lbs. He places a 0.454 kg weight on one side of a balance scale and a 1.00 lb weight on the other side. What will happen to the balance when it is released? Explain what this tells us physically about the two quantities 0.454 kg and 1.00 lbs.

3. **Reason.** There is one number we can multiply a measurement by without changing the size of the physical quantity it represents. What is that number?

The process of conversion between two sets of units leaves the physical quantity unchanged – the number and unit parts of the measurement will both change, but the result is always the same physical quantity (the same amount of stuff), just described in a different way. To make sure we don't change the actual physical quantity when converting, we only ever multiply the measurement by "1". We multiply the quantity by a *conversion ratio* which must always equal "1".

$$m = 0.454\,\cancel{\text{kg}}\left(\frac{2.204\,lbs}{1.00\,\cancel{kg}}\right) = 1.00\text{ lbs or 1 lb} \qquad v = 65\,\frac{km}{\cancel{h}}\left(\frac{1.000\,\cancel{h}}{3600\,s}\right) = 0.0180\text{ km/s}$$

The ratio in the brackets is the conversion ratio. Note that the numerator and denominator **are equal**, making the ratio equal to "1". It is usually helpful to complete your conversions in the first step of your problem solving.

4. **Explain.** Examine the conversion ratios in the example above. When converting, you need to decide which quantity to put on the top and the bottom of the fraction. Explain how to decide this. A hint comes from the markings and units in the examples above.

5. **Reason.** You are trying to convert a quantity described using minutes into one described using seconds. Construct the conversion ratio you would use and explain why it will work.

B: The Practice of Conversions

1. **Solve**. Convert the following quantities. Carefully show your conversion ratios and how the units divide out. **Remember to use our guidelines for significant digits!**

Convert to seconds	Convert to kilometres
Δt = 12.5 minutes $\left(\frac{\quad}{\quad}\right)$=	Δx = 4.5 m $\left(\frac{\quad}{\quad}\right)$=

2. **Reason.** In the previous question, you converted from minutes to seconds. Explain in a simple way why it makes sense that the quantity measured in seconds is a bigger number.

3. **Reason.** You are converting a quantity from kilograms into pounds. Do you expect the number part to get larger or smaller? Explain.

4. **Solve**. Convert the following quantities. Carefully show your conversion ratios and how the units divide out. Don't forget those sig. dig. guidelines!

Convert to kilograms	Convert to seconds
m = 138 lbs $\left(\frac{\quad}{\quad}\right)$=	Δt = 3.0 days $\left(\frac{\quad}{\quad}\right)\left(\frac{\quad}{\quad}\right)$=

5. **Reason.** You are converting a quantity from km/h into m/s. How many conversion ratios will you need to use? Explain.

Convert to m/s	Convert Penny's finishing race speed to km/h
$v = 105\ \frac{km}{h}\left(\frac{\quad}{\quad}\right)\left(\frac{\quad}{\quad}\right)=$	$v = 1.98\ \frac{m}{s}\left(\frac{\quad}{\quad}\right)\left(\frac{\quad}{\quad}\right)=$

6. **Conversion Challenge.** Choose an interesting object that belongs to your group. Your teacher has a collection of small weights. Your challenge is to assemble a group of weights that has the same mass as your interesting object. The trick is, the collection of weights are all measured in grams, and the digital balance scale only measures in ounces! (1 pound = 16 ounces) Go! When you are ready, test your result for your teacher. A good result will agree with the original measurement to within ± 0.1 oz.

SPH3U: Modeling Solutions to Problems

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Creating a model of a system and using it to make predictions requires thought and care. In our physics course, we do this using a five-part process. Let's return to Penny`s gold-medal race and explore an example of this process.

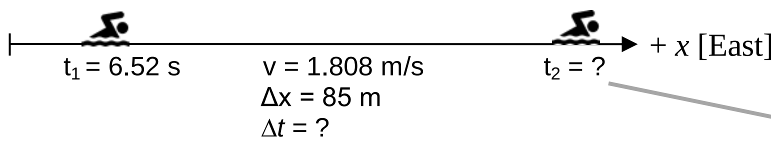
Manager: Help your group read carefully through this example. Members can take turns reading. Don't skip anything!

Problem: Penny dives into the pool and reaches the surface after swimming under water for 6.52 s. Then she swims the remaining 85 m of the race with a steady speed of 1.808 m/s. According to this model, what is her time for the entire race?

A: Pictorial Representation (of Model)

~~Sketch showing events~~, ~~describe events~~, ~~coordinate system~~, ~~label givens & unknowns with symbols~~, ~~conversions~~

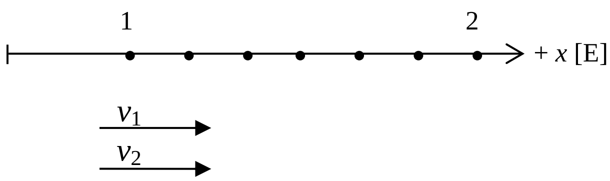
Event 1 = she reaches surface   Event 2 = she reaches the finish

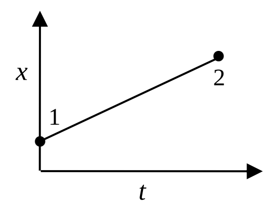


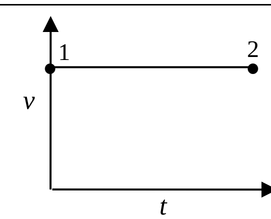
Notice how each quantity has a symbol assigned to it and is attached to the appropriate part of the sketch.

B: Physics Representation (of Model)

~~Motion diagram~~, ~~motion graphs~~, ~~velocity vectors~~, ~~events~~







C: Word Representation (of Model)

~~Describe motion (no numbers)~~, ~~assumptions~~, ~~estimated result (no calculations)~~

She swims east (the positive direction). We assume Penny is a point particle and has a constant velocity. I estimate it will take her about 40 seconds to swim this distance.

D: Mathematical Representation (of Model)

~~Describe physics of steps~~, ~~complete equations~~, ~~algebraically isolate~~, ~~substitutions with units~~, ~~final statement of prediction~~

Find Penny's time to swim the remaining distance:

$v = \Delta x / \Delta t$

$\therefore \Delta t = \Delta x / v$

$= (85\ \text{m})/(1.808\ \text{m/s}) = 47.01\ \text{s}$

A good description mentions what is happening (swimming the rest of the distance), the object (Penny), and what you want to find (time) without using symbols.

Find the time for her entire race:

$\Delta t = t_2 - t_1$

$\therefore\ t_2 = t_1 + \Delta t$

$= 6.52\ \text{s} + 47.01\ \text{s}$

$= 53.53\ \text{s}$

Always isolate the unknown variable you want to find before you substitute any values into your equation. The list of steps under part D above is meant to be done in that order.

According to this model, I predict her race time will be 53.5 s.

A physics calculation based on a model is always a prediction. It tells us what should happen, *according to the model*. The reliability of this prediction depends on the assumptions of the model and the quality of the data.

E: Evaluation (of Prediction)

~~Answer has reasonable size~~, ~~direction~~ and ~~units~~? ~~Explain why~~.

The size of her time is reasonable: since she is moving slowly, it will take her a while to finish the race. Time does not have a direction. Seconds are reasonable units for a short interval of time.

1. **Explain.** Why do the given and unknown quantities have these positions in the sketch of this example?

2. **Reason.** Imagine you could only see part A of the solution. How could you decide if any conversions are necessary for the solution? Explain.

3. **Describe.** Event 1 in this problem does not occur at the origin for position measurements. There are three ways that this is shown in the solution. Describe these three ways.

When we solve a problem using this solution process, we can check the quality of our solution by looking for *consistency*. For example, if the object is moving with a constant velocity we should see that reflected in many parts of the solution. If the object is moving in the positive direction, we should see that reflected in many parts. Always check to see that the important physics ideas are properly reflected in all parts of the solution.

4. **Interpret.** Our swimmer in this problem is swimming in the positive direction. List all the ways this is shown in the solution.

5. **Interpret.** Penny swims with a constant velocity. List all the ways this is shown in the solution.

A new step in the explanation process for calculations (what we are now calling the *Mathematical Representation*) is the step "*algebraically isolate*". Before we substitute any numbers into an equation, we will isolate the unknown variable on one side of the equation using symbols. Exercise those algebra skills you have worked so hard on in math class!

6. **Explain.** Carefully show all the mathematical steps used to rearrange the velocity equation to solve for time. Make sure you show how quantities divide away. (Note: the work shown in the sample solution is all you need to do in the future)
$v = \frac{\Delta x}{\Delta t}$

7. **Explain.** Why can it be helpful to do the work isolating a quantity (like t_2 or Δt in the example above) using only symbols and waiting until <u>after</u> that is done before substituting any values into the equation?

8. **Evaluate.** The evaluation step is a final check to help us decide whether our model and its assumptions seem reasonable. Suppose a friend of yours came up with a final time of 8.9 s. Aside from an obvious math error, why is this result not reasonable in size?

B: Problems Unsolved

Use the new process to model a solution for the following problems. Use the blank solution sheet on the next page. To conserve paper, some people divide each page down the centre and do two problems on one page.

1. In a record-breaking race, Usain Bolt took 50 m to reach his top speed. After that, he ran the next 150 m of his race in 13.59 s. What is his speed in km/h during the last past of his race?

The next problem involves <u>vertical</u> motion. Draw your sketch vertically and use the symbol y instead of x for the position. For this problem, choose upwards as the $+y$ direction and the ground as the origin.

2. In February 2013, a meteorite streaked through the sky over Russia. A fragment broke off 35 km above the surface of the earth and traveled downwards with a velocity of -12 000 km/h. It exploded 10 s after breaking off. How far above the earth was the meteorite when it exploded? (Hint: set y_1 = 35 km and watch for the negative velocity!)

Answers: (1) 39.7 km/h, (2) 1.67 km

Motion Solution Sheet	Name:	Problem:

A: Pictorial Representation

Sketch showing events, describe events, coordinate system, label givens & unknowns using symbols, conversions

B: Physics Representation

Motion diagram, motion graphs, velocity vectors, events

C: Word Representation

Describe motion (no numbers), assumptions, estimated result (no calculations)

D: Mathematical Representation

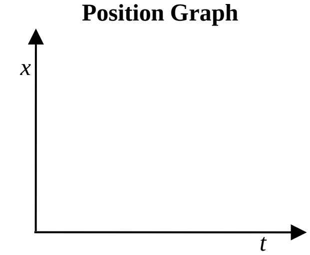
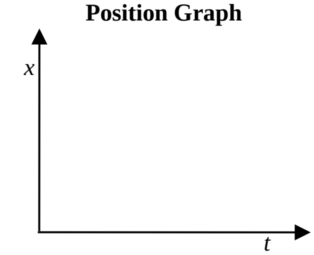
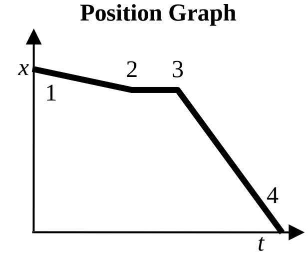
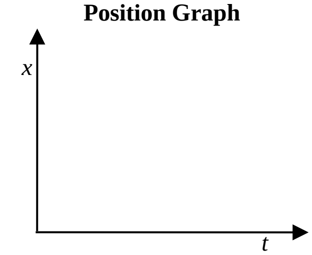
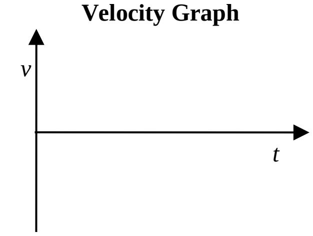
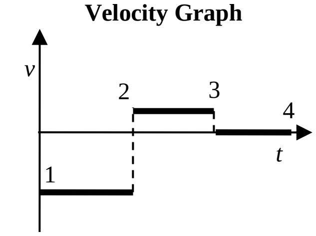
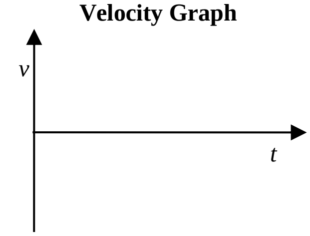
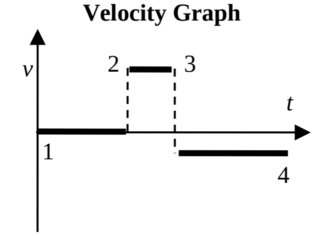
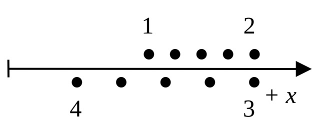
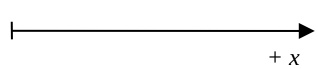
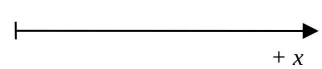
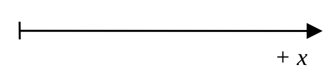
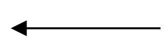
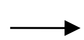
Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

E: Evaluation

Answer has reasonable size, direction and units? Explain why.

Homework: Representations of Motion

Each column in the chart below shows five representations of one motion. The small numbers represent the events. Here are some hints for the **motion diagrams**: (a) If the object remains at rest, the two events will be located at the same position on a motion diagram (see situation 1), (b) if it changes direction, shift the dots just above or below the axis (see situation 1), (c) remember that the origin is marked by a small vertical line. There is at least one completed example of each type of representation that you can use as a guide. The positive *x*-direction is east.

Situation 1	Situation 2	Situation 3	Situation 4
Description 1-2: 2-3: 3-4:	**Description** 1-2: 2-3: 3-4:	**Description** 1-2: 2-3: 3-4:	**Description** 1-2: It starts at the origin and remains at rest for a while. 2-3: It moves quickly in the positive direction (east) with a constant velocity 3-4: It moves slowly in the negative direction (west) with a constant velocity.
Position Graph 	**Position Graph** 	**Position Graph** 	**Position Graph** 
Velocity Graph 	**Velocity Graph** 	**Velocity Graph** 	**Velocity Graph** 
Motion Diagram 	**Motion Diagram** 	**Motion Diagram** 	**Motion Diagram** 
Velocity Vectors (velocity during each interval) 1-2: 2-3: 3-4:	**Velocity Vectors** (velocity during each interval) 1-2:  2-3:  3-4:	**Velocity Vectors** (velocity during each interval) 1-2: 2-3: 3-4:	**Velocity Vectors** (velocity during each interval) 1-2: 2-3: 3-4:

SPH3U: Changing Velocity

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

We have explored the idea of velocity and now we are ready to test it carefully and see how far this idea goes. As you work through this investigation remember how we have interpreted the velocity ratio $\Delta x/\Delta t$ so far:

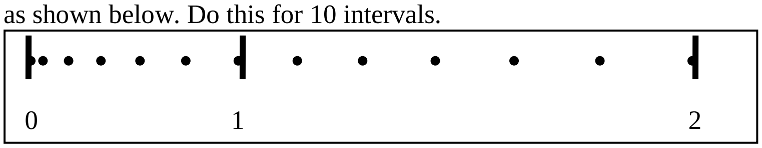
"The quantity $\Delta x/\Delta t$ tells us how far and in what direction the object travels every second. For example: -3m/s means that for every second that goes by, the object travels 3 metres in the negative direction."

A: Motion with Changing Velocity

Your teacher has a tickertape timer, a cart and an incline set-up. Turn on the timer and then release the cart to run down the incline. Bring the tickertape back to your table to analyze.

1. **Observe**. Examine the pattern of dots on your tickertape. How can you tell whether or not the velocity of the cart was constant?

2. **Find a Pattern.** From the **first dot** on your tickertape, draw lines that divide the dot pattern into intervals of six *spaces* as shown below. Do this for 10 intervals.



3. **Reason.** The timer is constructed so that it hits the tape 60 times every second. How much time does each six-space interval take? Explain your reasoning.

4. **Reason.** Albert makes a calculation of the velocity ratio $\Delta x/\Delta t$ for the interval of his entire dot pattern on the ticker tape. He says, "My result is 53 cm/s. This means that for every second that goes by, the cart moves 53 cm in the positive direction." Do you agree or disagree with Albert? Explain.

When the velocity is noticeably changing during a time interval Δt, we cannot use our simple interpretation of the ratio $\Delta x/\Delta t$. Instead, we call the ratio $\Delta x/\Delta t$ the *average velocity*. This is our first hint that changing velocity is a very different *state of motion* than constant velocity. We need to develop a more powerful interpretation for the ratio $\Delta x/\Delta t$ in this new state of motion.

B: Analyzing Motion with Changing Velocity

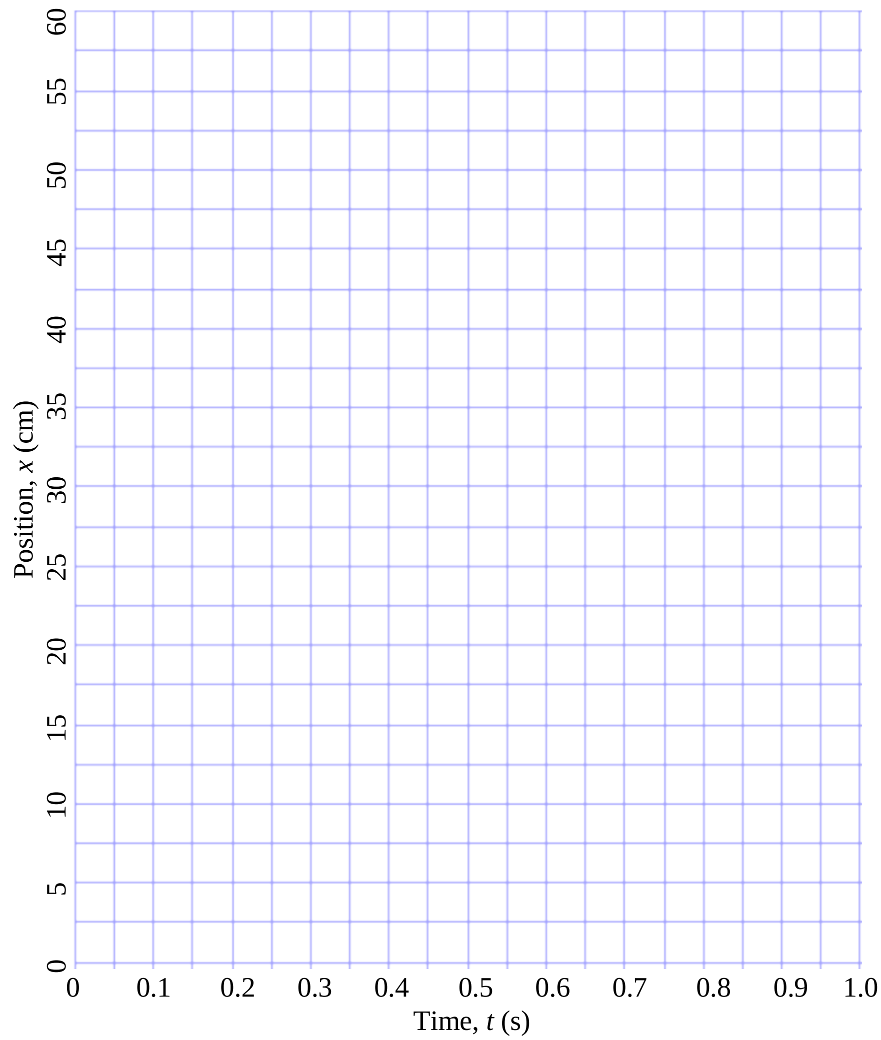
On the next page are a chart for your position-time data and a grid for your graph. Follow the instructions below.

1. **Measure.** Collect a complete set of position and time data from your tickertape. **Each** position measurement should start from the first mark "0" you make. Record your data in the chart on the next page.

2. **Reason.** What is the uncertainty in your position measurements?

3. **Find a Pattern.** Plot the data in a graph of position vs. time. Does the data seem to follow a straight-line pattern or a curve? Explain.

Time, *t* (s)	Position, *x* (cm)
0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1.0	



Smooth Curve. When data follows a curving pattern, we draw a smooth curve to fit the data. Just like with lines of best-fit, we do not want to connect the dots and create a zig-zag pattern. Draw a smooth curve through most of the data points, but don't try to connect points that do not fit into your smooth curve.

4. **Explain.** We will focus on the time interval from 0 to 1.0 seconds. During this time interval:
   (a) How do the spaces between the ticker tape dots show that the velocity is changing?

   (b) How does the position data in the chart above show that the velocity is changing?

   (c) Draw a straight line on your position graph that connects with your smooth curve at 0 and 1.0 s (or your last data point). How can you tell that the velocity during this time interval is not constant?

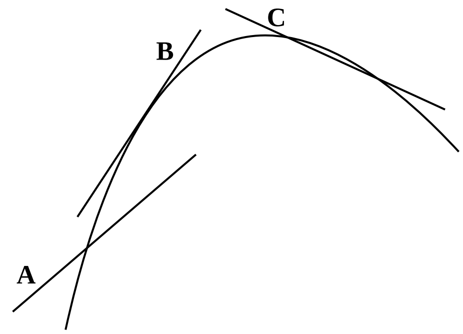
5. **Explain.** We will focus on a smaller interval of time, near the middle of your set of data, for example from 0.4 to 0.6 s. Highlight this on your ticker tape. Imagine these are all the dots all you can see.
   (a) When you examine the ticker-tape dots, is it easier or harder to decide if the velocity is changing? Why?

   (b) Draw a straight line on your position graph that connects with your smooth curve at 0.4 and 0.6 seconds. Is it easier or harder to decide if the velocity is changing during this interval? Why?

6. **Explain.** Now let's explore a very small interval, starting one single dot before 0.5 s and one single dot after 0.5 s. Highlight this on your tickertape. Imagine these are all the dots you can see. How hard is it now to decide if the velocity is constant?

As the time interval becomes smaller, the velocity within that interval appears more and more like constant velocity. We can always make the time interval smaller and smaller, and when we do that something remarkable happens: the line we have been drawing on our graph no longer appears to connect with the graph at two separate points. So we say that the line now touches the graph at one point. This type of line is called a *tangent*: a straight line that touches a curve at only one point without crossing over the curve.

7. **Apply.** Use the new definition of a tangent to explain which lines are tangent to the curve shown to the right and which are not.



8. **Represent and Reason.** Draw a tangent to your smooth curve such that it touches the curve at 0.5 s.
   (a) Now hold your ruler against your curve as if you were going to draw another tangent at 0.4s (don't draw it!). How does the slope of the tangent at 0.4 s compare with the one at 0.5 s?

   (b) Do the same for 0.6 s. How does this slope compare with 0.5 s?

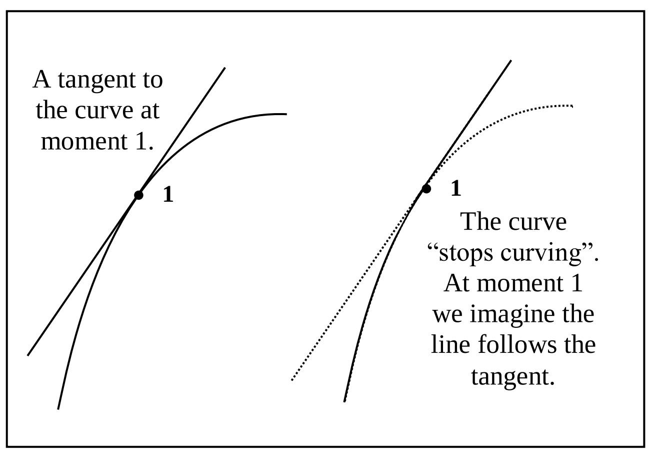
   (c) What quantity or characteristic of the cart's motion is changing each at every moment in time? (Hint: what does the slope of a position-time graph represent?)

The slope of the tangent to a curving position-time graph give the object's *instantaneous velocity*, meaning it's velocity at one moment (or instant) in time. This new type of velocity will be our focus for most of our work in physics. Since instantaneous velocities are different at different moments in time, it is helpful to label them with a subscript number that corresponds to the event. For example: v_1 = 12 m/s means the instantaneous velocity at moment 1 (the time of event 1).

9. **Calculate.** Label the point on your curve at 0.5 s event "1". Find the slope of the tangent to your curve. Hint: when you find the slope of any line, you will get a more reliable result (with less uncertainty) if you choose two points on the line that are **far apart**. Be sure to use physics symbols and show your units when you substitute the values.

The slope of a tangent is the same as the slope of the curve *at that point along the curve*. It might seem strange to think of a curve as having a slope, since it has no section that is straight. But we use a trick: the tangent allows us to imagine what the graph might look like if the curve stopped curving! So, the slope of the tangent equals the slope of the curve at that point along the curve.

This provides an important clue to help us interpret the meaning of the ratio $\Delta x/\Delta t$ for an instantaneous velocity: it tells how the object would move *if* the velocity stopped changing. For example: v_1 = +2 m/s means "At 0.5 seconds (the time of event 1), the object would travel 2 m in the positive direction every second if its velocity stopped changing."



10. **Interpret.** Use the description above to interpret the slope result for your tangent.

C: Summary of Velocity Ideas

We started this lesson with a simple idea of velocity. After exploring motion with changing velocity, we learned that we need to *refine* our velocity ideas in order to properly interpret the velocity ratio $\Delta x/\Delta t$ in this new situation. Here is a summary of what we have figured out.

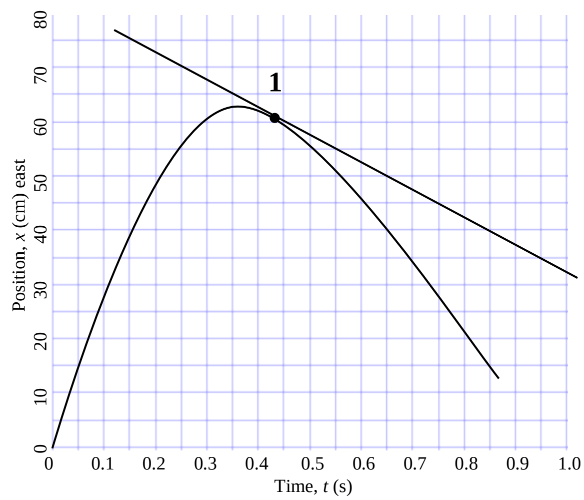
The Meaning of the Velocity Ratio $\Delta x/\Delta t$

State of Motion	Time Interval	Interpretation of Ratio	Label for Ratio
Constant Velocity	large	"*for every time interval* Δt*, the object* ***will*** *travel through a displacement* Δx"	velocity, v
Changing Velocity	large	When the velocity noticeably changes: "*during the time interval* Δt*, the object travels through a displacement* Δx"	average velocity, v_{avg}
	small (or just one moment in time)	When the velocity appears constant: "*for every time interval* Δt*, the object* ***would*** *travel through a displacement* Δx ***if*** *its velocity stopped changing*"	instantaneous velocity, v_1, v_2, etc.

The Language of Velocity. In the future, most of our physics work will focus on situations with changing velocity. As a result, we tend to get lazy and just say "velocity" when we really mean instantaneous velocity. You can always decide which velocity we mean by thinking about the state of motion and the time interval involved.

The magnitude (the number part without the direction) of the instantaneous velocity is the *instantaneous speed*. We will often use the word *speed* to refer to the size of the instantaneous velocity.

SPH3U: Changing Velocity Homework – Do This Now!



1. **Calculate.** Find the slope of the tangent to the curve at moment 1. This represents the instantaneous velocity at what moment in time?

2. **Interpret.** Draw three other tangents at different places on the graph.
   (a) Label them "faster" or "slower" compared with the tangent that was drawn for you.
   (b) Label the directions represented by the slopes of your tangents "east" or "west".

3. **Explain.** Is it possible to draw a tangent to this graph that represents an instantaneous velocity of zero? Explain and, if possible, draw.

4. **Explain.** At the beginning of her race, Penny Oleksiak dove into the water and swam under water for a 10-m distance. During this time, she was slowing down and at one moment had a velocity of 1.99 m/s. Explain how to use the summary chart above to decide what type of velocity this is.

5. **Interpret.** Google Maps told you that your drive trip to school involved traveling 3 km north and took 5 minutes. You use these values in a calculation of the velocity ratio. Explain how to use the summary chart above to decide what type of velocity this is.

SPH3U: The Idea of Acceleration

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

A: The Idea of Acceleration

Interpretations are powerful tools for making sense of calculations. Please answer the following questions by **thinking and explaining** your reasoning to your group, rather than by plugging into equations. Consider the situation described below:

A car was traveling with a constant velocity 20 km/h south. The driver presses the gas pedal and the car begins to speed up at a steady rate. The driver notices that it takes 3 seconds to speed up from 20 km/h to 50 km/h.

1. **Reason.** How fast is the car going 2 seconds after starting to speed up? Explain.

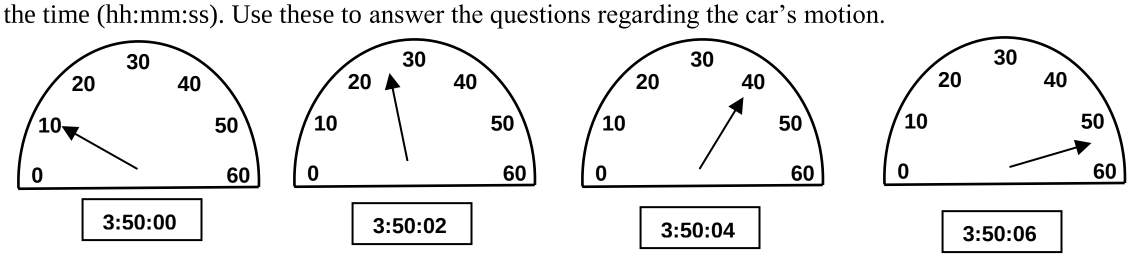
2. **Reason.** How much time would it take to go from 20 km/h to 80 km/h? Explain.

3. **Interpret.** A student who is studying this motion subtracts 50 – 20, obtaining 30. How would you interpret the number 30? What are its units?

4. **Interpret.** Next, the student divides 30 by 3 to get 10. How would you interpret the number 10? (Warning: don't use the word *acceleration*, instead explain what the 10 describes a change in. What are the units?)

B: Watch Your Speed!

Shown below are a series of images of a speedometer in a car showing speeds in km/h. Along with each is a clock showing the time (hh:mm:ss). Use these to answer the questions regarding the car's motion.



1. **Reason.** What type of velocity (or speed) is shown on a speedometer – average or instantaneous? Explain.

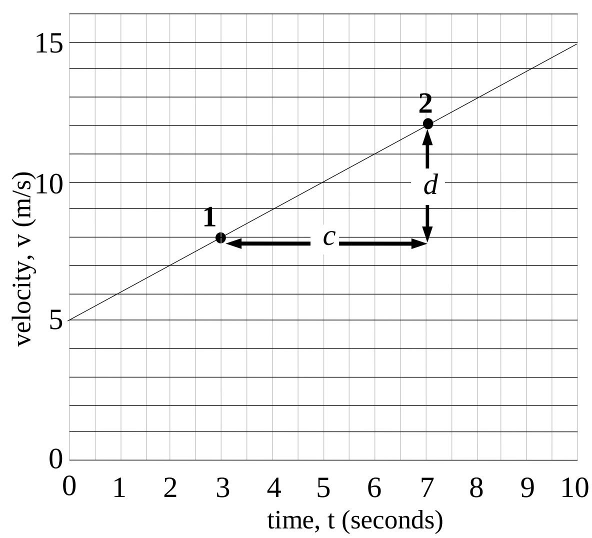
2. **Explain.** Is the car speeding up or slowing down? Is the change in speed steady?

3. **Explain and Calculate.** Explain how you could find the acceleration of the car. Calculate this value and write the units as (km/h)/s.

4. **Interpret.** Albert exclaims, "In our previous result, why are there two different time units: hours and seconds? This is strange!" Explain to Albert the significance of the hours unit and the seconds unit. The brackets provide a hint.

C: Interpreting Velocity Graphs

To the right is the velocity versus time graph for a particular object. Two moments, 1 and 2, are indicated on the graph.



1. **Interpret.** What does the graph tell us about the object at moments 1 and 2?

2. **Interpret.** Give an interpretation of the interval labelled c. What symbol should be used to represent this?

3. **Interpret.** Give an interpretation of the interval labelled d. What symbol should be used to represent this?

4. **Interpret.** Give an interpretation of the ratio d/c. How is this related to our discussion in part A?

5. **Calculate.** Calculate the ratio d/c including units. Write the units in a similar way to question B#3.

6. **Explain.** Use your grade 8 knowledge of fractions to explain how the units of (m/s)/s are simplified.

$$(m/s)/s = \frac{m}{s} \div s = \frac{m}{s} \div \frac{s}{1} = \frac{m}{s} \times \frac{1}{s} = m/s^2$$

SPH3U: Calculating Acceleration

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

A: Defining Acceleration

The quantity calculated from the slope of the velocity graph in last class's investigation is called the *acceleration*. The motions shown in parts A, B and C of that investigation all have the characteristic that the velocity of the object changed by the same amount in equal time intervals. When an object's motion has this characteristic, we say that the object has *constant acceleration.* We can therefore interpret the number $\Delta v/\Delta t$ as the *change* in velocity occurring in each unit of time. The number, $\Delta v/\Delta t$, is called the *acceleration* and is represented by the symbol, a.

$$a = \Delta v/\Delta t = \frac{v_f - v_i}{t_f - t_i}\text{, if the acceleration is constant}$$

In Gr. 11 physics, we will focus on situations in which the acceleration is constant (sometimes called *uniform acceleration*). Acceleration can mean speeding up, slowing down, or a change in an object's direction - any change in the velocity qualifies! In the equation above, we wrote v_f and v_i for the final and initial velocities during some interval of time. If your time interval is defined by events 2 and 3, you would write v_3 and v_2 for your final and initial velocities.

1. **Explain.** We mentioned earlier that the "Δ" symbol is a short form. In this case, explain carefully what Δv represents using both words and symbols.

B: You've Got Problems!

1. Your teacher has a cart set up on a track at the front of the room. The cart is equipped with a fan that causes it to accelerate. Your teacher will release the cart and use the motion detector to measure to display a graph of its velocity. You may choose what moments in time and what values from the graph to use. **What is the cart's acceleration?** (You can check your answer by using the computer to find the slope of the velocity graph.)

A: Pictorial Representation

Sketch showing events, coordinate system, label givens & unknowns using symbols, conversions, describe events

B: Physics Representation

Motion diagram, velocity graph, velocity vectors, events

C: Word Representation

Describe motion (no numbers), assumptions, estimated result (no calculations)

D: Mathematical Representation

Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

In the previous example, if you did your work carefully you should have found units of m/s^2 for the acceleration. It is important to understand that the two units of time in (m/s)/s (m/s^2 is shorthand) play different roles. The *second* in m/s is just part of the unit for velocity (like *hour* in km/h). The other *second* is the unit of time we use when describing how much the velocity changes in one unit of time.

For convenience, our new equation for acceleration is often written as: $v_f = v_i + a\Delta t$

2. **Explain.** Show the algebraic steps that start from the equation $a = \Delta v/\Delta t$ and lead to $v_f = v_i + a\Delta t$.

3. **Hit the Gas!** You are driving west along the 401 and want to pass a large truck. You floor the gas pedal and begin to speed up. You start at 102 km/h, accelerate at a steady rate of 2.9 (km/h)/s (obviously not a sports car). What is your velocity after 5.3 seconds when you finally pass the truck?

A: Pictorial Representation

Sketch showing events, coordinate system, label givens & unknowns using symbols, conversions, describe events

Check: did you replace "i" and "f" in your symbols with event numbers?

B: Physics Representation

Motion diagram, velocity graph, velocity vectors, events

C: Word Representation

Describe motion (no numbers), assumptions, estimated result (no calculations)

D: Mathematical Representation

Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

E: Evaluation

Answer has reasonable size, direction and units? Explain why.

4. **The Rocket** A rocket is travelling upwards. A second engine begins to fire causing it to speed up at a rate of 21 m/s^2. After 4.3 seconds it reaches a velocity of 413 km/h and the engine turns off. What was the velocity of the rocket when the second engine began to fire?

To describe motion in the vertical direction, use the symbol *y* for the *vertical* position. All other symbols remain the same. In physics, the symbol *x* will only be used for *horizontal* position. The sketch for the situation should show the vertical motion and the coordinate system should show which vertical direction is the +*y*-direction. The motion diagram and the velocity vectors should point vertically.

A: Pictorial Representation

Sketch showing events, coordinate system, label givens & unknowns using symbols, conversions, describe events

B: Physics Representation

Motion diagram, velocity graph, velocity vectors, events

C: Word Representation

Describe motion (no numbers), assumptions, estimated result (no calculations)

D: Mathematical Representation

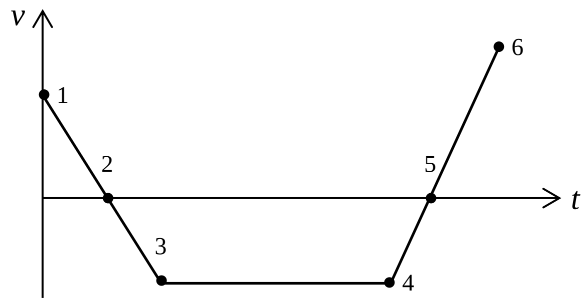
Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

E: Evaluation

Answer has reasonable size, direction and units? Explain why.

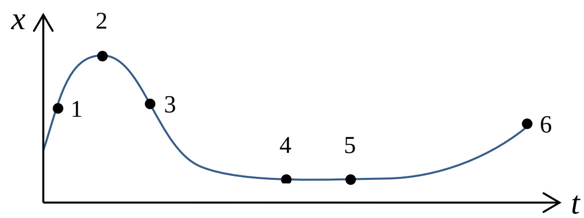
Homework: Speeding Up and Slowing Down

1. **Interpret and Explain.** A person walks back and forth in front of a motion detector producing the velocity graph shown to the right. Six events have been labelled on the graph. The chart below lists different examples of motion. Find the appropriate interval(s) of time in the graph that correspond to that type of motion and **provide evidence from the graph** supporting your choice**.**



Type of motion	Interval(s)	Evidence
positive acceleration		
negative acceleration and a positive velocity		
acceleration of zero		
speeding up		
slowing down		
at rest (reminder: at rest means not moving for an **interval** of time)		
Change of acceleration	Moments:	

2. **Interpret and Explain.** In a different experiment, a person walks back and forth in front of a motion detector and produces the position graph shown to the right. The chart below lists different examples of motion. Find the appropriate interval(s) of time or events in the graph that correspond to that type of motion and **provide evidence from the graph** supporting your choice**.**



Type of motion	Intervals or Events	Evidence
Zero velocity		
Speeding up		
Slowing down		
Turning around		

Quality Work Criteria	Mark /5
My responses use thoughtful, complete sentences and are very easy to read.	
For each response, I mentioned specific features of the graphs as my evidence	
This work would be useful for **any** student to study from in the future.	

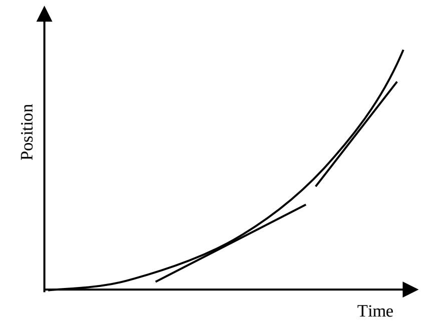
SPH3U: Speeding Up or Slowing Down?

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

There is one mystery concerning acceleration remaining to be solved. Our definition of acceleration, $\Delta v/\Delta t$, allows the result to be either positive or negative, but what does that mean? Today we will get to the bottom of this.

A: Acceleration in Graphs

Your teacher has set-up a cart with a fan on a dynamics track and a motion detector to help create position-time and velocity-time graphs. Let's begin with a position graph before we observe the motion. The cart is initially moving forward. The fan is on and gives the cart a steady, gentle push which causes the cart to accelerate.



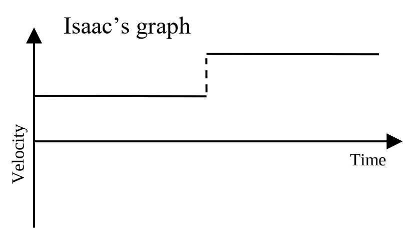
1. **Reminder.** What does the slope of a tangent to any position-time graph represent?

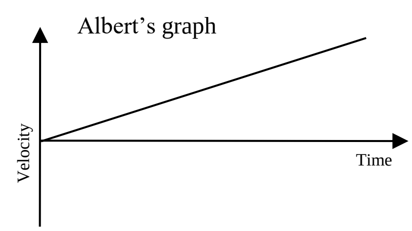
2. **Interpret.** Is the cart speeding up or slowing down? Use the two tangents to the graph to help explain.

To help interpret position graphs, we will use the *tangent trick*. Use a ruler or pencil as the tangent line to a position graph. Interpret the slope of the tangent. Then move the tangent to a new spot along the graph and interpret. Decide if the object is speeding up or slowing down. This trick can also be used decide how to sketch a position graph.

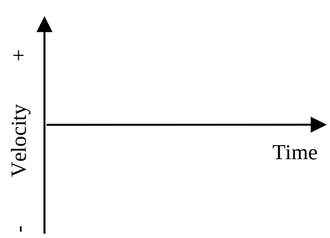
3. **Reason.** Is the change in velocity positive or negative? What does this tell us about the acceleration?

4. **Reason.** Two students draw a velocity graph based on the position graph above. Which graph do you think best matches the position graph? Explain.





5. **Test and interpret.** *(as a class*) Observe the velocity-time graph produced by the computer for this situation. Interpret the motion shown in the velocity graph. **In all the following examples, east is the positive direction.**

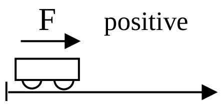
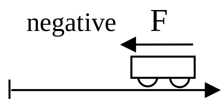
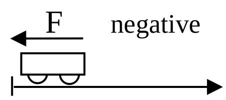
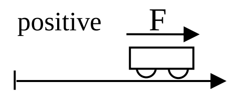
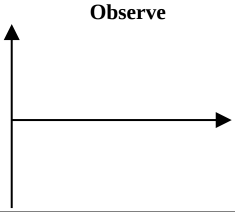
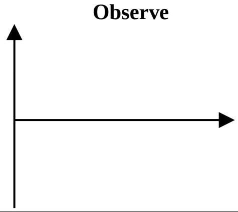
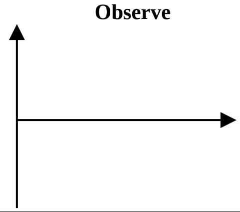
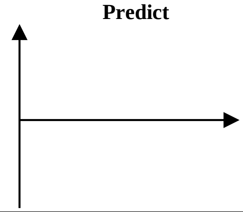
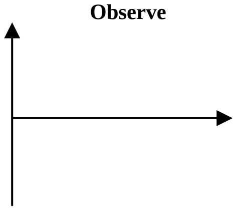
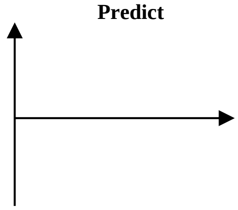
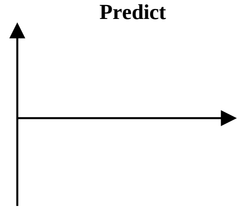
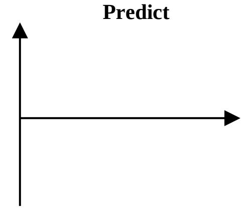
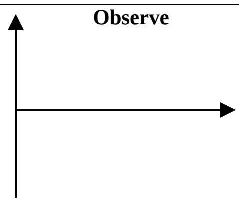
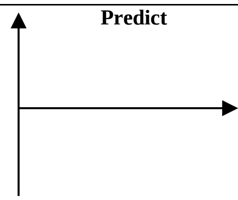
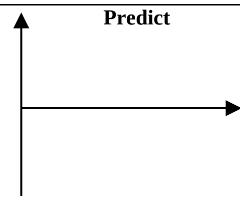
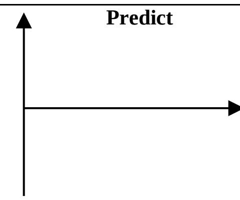


Feature	Value	Meaning
Type of graph		
Sign of velocity values		
Size of velocity values		
Shape of graph		
Slope of graph		

B: The Sign of the Acceleration

Your teacher has a cart with a fan set up on a track.

1. **Observe, Predict and Interpret.** *(as a class)* Your teacher will lead you through four different situations involving the cart. You will make observations, make prediction and interpret the results using the chart on the next page.

Situation	**1**	**2**	**3**	**4**
Description	The cart is released from rest near the motion detector. The fan exerts a force on the cart pointing **away** from the detector.	The cart is released from rest far from the detector. The fan exerts a force on the cart **towards** the detector.	The cart is moving away from the detector. The fan exerts a force on the cart **towards** the detector.	The cart is moving towards the detector. The fan exerts a force on the cart **away** from the detector.
Sketch with Force				
Position graph	**Observe** 	**Observe** 	**Observe** 	**Predict** 
Velocity graph	**Observe** 	**Predict** 	**Predict** 	**Predict** 
Acceleration graph	**Observe** 	**Predict** 	**Predict** 	**Predict** 
Slowing down or speeding up?				
Sign of Velocity				
Sign of Acceleration				

2. **Reason.** Emmy says, “We can see from these results that when the acceleration is positive, the object always speeds up.” Do you agree with Emmy? Marie says, “No. There’s more to it than that.” Who do you agree with? Explain.

3. **Reason.** What conditions for the acceleration and velocity must be true for an object to be speeding up? To be slowing down?

4. **Reason.** The sign of the acceleration **always** matches the sign of what other quantity in our chart?

Always compare the magnitudes of the velocities (the speeds) using the terms *faster* or *slower*. Describe the motion of accelerating objects as *speeding up* or *slowing down* and state whether it is moving in the positive of negative direction. Other ways of describing velocity often lead to ambiguity and trouble! **Never** use the d-word (*deceleration*) - yikes! Note that we will always assume the acceleration is uniform (constant) unless there is a good reason to believe otherwise.

5. **Reason.** In situation #4, why might it be confusing to interpret the velocity graph by saying, “the velocity is increasing”? What might be better to say?

SPH3U: Area and Displacements

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

A graph is more than just a line or a curve. We will discover a very handy new property of graphs which has been right under our noses (and graphs) all this time!

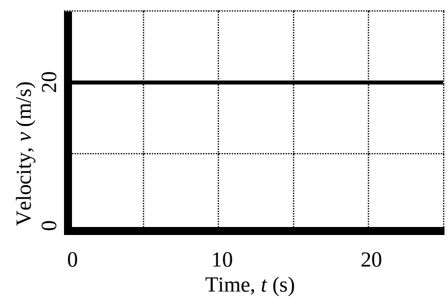
A: Looking Under the Graph

A car drives south along a straight road at 20 m/s. After 5 s the car passes a streetlight and at 20 s the car passes a stop sign.

1. **Describe.** Based on what you have learned so far in physics, how can we calculate the displacement of the car between the streetlight and the stop sign?

2. **Reason.** Suppose instead that the car's starting velocity was 20 m/s and at 0 s the car began to speed up. In the same 15-s time interval, would the car's displacement be larger or smaller? Explain.

3. **Sketch.** Now we will think about this calculation in a new way. Draw and shade a rectangle on the graph that fills in the area between the line of the graph and the time axis, for the time interval of 5 to 20 seconds.



4. **Describe.** In math class, how would you calculate the area of the rectangle?

5. **Interpret.** Calculate the area of the rectangle. Note that the length and width have a meaning in physics, so the final result is not a physical area. Use the proper physics units that correspond to the height and the width of the rectangle. What physics quantity does the final result represent?

The *area* under a velocity-time graph for an interval of motion gives the *displacement* during that interval. Both velocity and displacement are vector quantities and can be positive or negative depending on their directions. According to our usual sign convention, areas above the time axis are positive and areas below the time axis are negative.

B: Applying Our New Tool

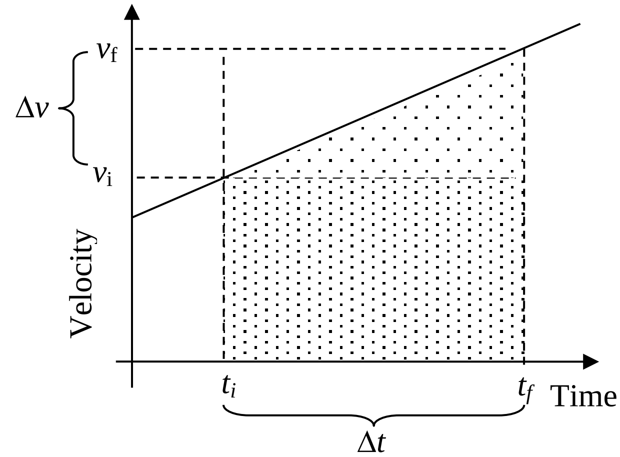
Our new tool for finding displacements will help us find the answer to a sticky problem: how can we find the displacement of an accelerating object?

Consider the graph on the next page that shows the velocity of an object that is speeding up. We want to use this graph to find the displacement of the object between the times t_i and t_f. The area under this graph has an unusual shape, but we can split up the area into two simpler shapes.

1. **Represent.** How do we find the area of any rectangle? Write an expression for the area the way you would write it in math class. How can we find the area of the rectangle under this graph? Write a new expression for the area using physics symbols from this graph.

   math class expression: area =

   physics graph expression: area =



2. **Represent.** Write an expression for the area of the triangle in two different ways..

   math class expression: area =

   physics graph expression: area =

Our goal is to create an equation that lets us find the displacement of the object if we know its acceleration. To do that, we need to do a math trick.

3. **Represent.** Remember our definition of acceleration: $a = \Delta v/\Delta t$. If we rearrange it, we have: $\Delta v = a\Delta t$. Make a mathematical substitution for Δv in your physics graph expression for the area of the triangle. Do a bit of algebra work to simplify your expression.

   area =

4. **Represent.** Create one expression that describes the *total* area underneath the graph.

   area =

5. **Interpret.** We understand that the area under the graph between those moments in time represents the displacement of the object. Write a final version of your equation. Replace the word "area" with the appropriate physics symbol.

** call your teacher over to check your equation **

The equation you have just constructed is one of the five equations for constant acceleration (affectionately known as the BIG five). Together they help relate different combinations of the five variables of motion: Δx, a, v_i, v_f and Δt. You have encountered one other BIG five so far, (in a disguised form) the definition of acceleration: $a = \Delta v/\Delta t$. Recall that this equation was also constructed by analyzing a graph showing changing velocity! Awesome!

6. Evaluate. Would the new equation produce a result that agrees with your response for question A#2? Explain.

Displacement Problems!

Use the full solution format to solve these problems. Hint: when choosing an equation (you have a choice of two), think about which quantities you know and which you are trying to find out.

1. **Taking Off.** A jumbo jet takes flight while travelling down a 1.80 km runway. It barely makes it off the ground after it reaches the end of the runway, taking 37.9 s of time. What is the acceleration of this jet? Give your answer in m/s^2

2. **Stopping a Muon.** A muon (a subatomic particle) moving in a straight line enters a detector with a speed of 5×10^6 m/s and then it slowed down at the rate of 1.25×10^{14} m/s^2 in 4×10^{-8} s. How far does it travel while slowing down? (Hint: to slow down, one of your vector quantities will need to be negative. Which one?)

Answers: (1) 2.51 m/s^2, (2) 0.1 m

SPH3U: The BIG Five

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Last class we found three equations to help represent motion with constant acceleration. A bit more work along those lines would allow us to find two more equations which give us a complete set of equations for the five kinematic quantities.

A: The BIG Five – Revealed!

Here are the BIG five equations for uniformly accelerating motion (the acceleration is constant).

The **BIG** Five	v_i	v_f	Δx	a	Δt
$v_f = v_i + a\Delta t$					
$\Delta x = v_i\Delta t + ½a\Delta t^2$					
$\Delta x = v_f\Delta t - ½a\Delta t^2$					
$\Delta x = ½(v_i + v_f)\Delta t$					
$v_f^{\,2} = v_i^2 + 2a\Delta x$					

1. **Observe.** Fill in the chart with √ and × indicating whether or not a kinematic quantity is found in that equation.

2. **Find a Pattern.** How many quantities are related in each equation?

3. **Reason.** If you wanted to use the first equation to calculate the acceleration, how many other quantities would you need to know?

4. **Describe.** Define carefully each of the kinematic quantities in the chart below.

v_i	
v_f	
Δx	
a	
Δt	

5. **Reason.** What condition must hold true (mentioned in the previous investigation) for these equations to give reasonable or realistic results?

B: As Easy as 3-4-5

Solving a problem involving uniformly accelerated motion is as easy as 3-4-5. As soon as you know **three** quantities, you can always find a **fourth** using a BIG **five**! Write your solutions carefully using our solution process. Use the chart to help you choose a BIG five. Here are some sample problems that we will use the BIG five to help solve. Note that we are focusing on certain steps in our work here – in your homework, make sure you complete all the steps!

1. **Solve.** Your teacher has an inclined track set up at the front of the room. Your teacher will release a cart from rest at the top of the track. Your group must choose a position along the track. Label this position with a sticky-note that includes your group number and the displacement of the cart when it reaches that position. Your challenge is to predict the cart's speed at that position. Your teacher will give you the cart's acceleration. When you are finished, add your prediction to your sticky-note.

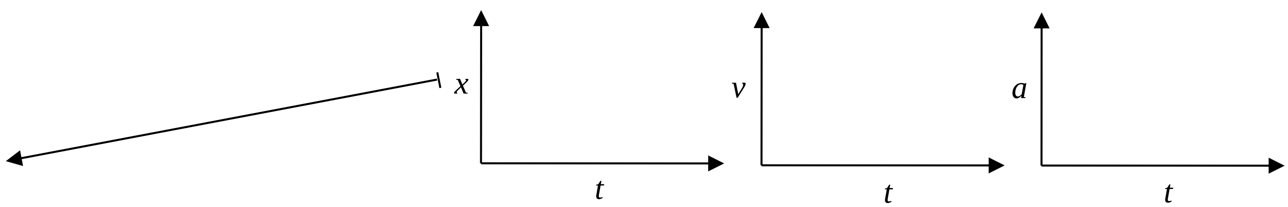
A: Pictorial Representation

Sketch showing events, coordinate system, label givens & unknowns with symbols, conversions, describe events

Emmy says, "I know only two numbers, the acceleration and displacement. I need three to solve the problem. I'm stuck!" Explain how to help Emmy.

B: Physics Representation

Motion diagram, motion graphs, velocity vectors, events



D: Mathematical Representation

Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

C: You've Got Problems: Complete these problems on a separate solution sheet

(1) **Crash Test.** An automobile safety laboratory performs crash tests of vehicles to ensure their safety in high-speed collisions. The engineers set up a head-on crash test for a Smart Car which collides with a solid barrier. The engineers know the car initially travels south at 100 km/h and the crash test dummy moves 0.78 m south during the collision. The engineers have a couple of questions: How much time does the collision take? What is the passenger's acceleration during the collision?

(2) **Microscopic physics.** All cell biology works according to the laws of physics! A sodium ion (3.817×10^{-26} kg) arrives near an opening in a cell. You may assume it is initially at rest. Electric forces cause it to speed up and travel towards the cell opening. As a result, it travels 1.48×10^{-7} m in 0.512 s. What is the acceleration of the sodium ion?

(3) **Off the Wall.** An important part of Penny's swim race is when she turns around while pushing on the swimming pool wall. When she makes contact with the wall, she is travelling at 1.66 m/s east. After pushing against the wall for 0.3 s, she leaves contact with it and is travelling at 1.98 m/s west. What is her acceleration during this time?

(4) **The Track.** A cart is placed at the bottom of an inclined track. It uses a spring to launch itself up the incline with a speed of 0.79 m/s. While travelling up and down the incline, the cart has an acceleration of 0.54 m/s^2. How much time does it take to make the complete trip up and back down to its starting position? (Hint: this is a one-step problem)

Answers: (1) 0.0562 s, -495 m/s^2, (2) 1.13×10^{-6} m/s^2, (3) 12.1 m/s^2 west, (4) 2.93s

SPH3U: How to Study

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

There are many myths about how to study in school. Worst of all, you have probably seen students “not study” and still do very well. Students often rely on “study packages” from teachers and never learn how to properly prepare themselves for a quiz, test, or exam. This leads to great challenges outside of high school when the training wheels are off!

A: The Goals of Studying

There are two key questions that define our goals for studying:

(1) What am I responsible for knowing?
(2) What am I responsible for being able to do?

Studying involves answering these questions carefully and finding the practice you should complete to be confident with your learning under test conditions.

B: The Strategy of Studying

We will practice the process of studying using the conversions lesson from our motion unit (page 31). Take that page out of your handbook.

Core Ideas. You are responsible for knowing the core ideas from each lesson. In physics, these are usually (but not always) easy to find because that are highlighted in boxes! You can practice using the core ideas by (1) explaining the idea to another person, or (2) explaining how to use the idea in a certain situation.
Goal: To be able to carefully *explain* what is idea is and how to use it.

1. **Apply.** What are the core ideas for the conversions lesson? Briefly list them here. Write (Idea) beside each core idea in the margin of your handbook.

2. **Identify.** List a few sample questions from this lesson and homework, or from other lessons and homework that provide practice *explaining* each core idea.

Basic Skills. Basic skills are short tasks we repeatedly perform in physics. There are many basic skills in every unit of physics: e.g. drawing a motion diagram, isolating for an unknown quantity using symbols, and estimating a result. Basic skills are often introduced in one lesson and used in many others.
Goal: To be able to perform the basic skills *rapidly* and *accurately* in many different situations.

3. **Apply.** What are the basic skills introduced in this lesson? Briefly list them here. Write (Skill) beside each basic skill in the margin of your handbook.

4. **Identify.** List a few sample questions from this lesson and homework, or from other lessons and homework that provide practice with each the basic skill. Look for this skill in a variety of different situations and levels of difficulty.

Applications. We demonstrate our mastery of basic skills and core ideas when we successfully apply them to new situations. This often involves a combination of many skills and core ideas in one problem. Before we can quickly and reliably apply our understanding, we need to be confident with the core ideas and basic skills. Otherwise, applying your understanding will be slow and prone to error. Our physics course emphasizes application as the main way we evaluate your understanding of core ideas and basic skills.
Goal: To quickly and carefully *identify* what skills or ideas to use, and to use them *appropriately* in a new situation.

5. **Identify.** List a few sample questions from this lesson and homework, or from other lessons and homework that provide practice with this lesson's skills and ideas *combined* with other skills and ideas. Often these types of questions appear later in the unit and not in earlier lessons.

C: The Process of Studying

Life is short. People are busy. You need to learn how to manage your time so you can develop a good *process* for studying.

Studying is most effective when it is *broken up* across a number of days. This helps your brain make stronger connections between ideas through the magic combination of good sleep and careful study. It also gives you time to ask for help.

1. **Reflect.** Are your sleep habits any different the night before a test compared with other nights?

2. **Plan.** Choose three *specific* times on three *separate* days leading up to the test. Each time you should devote about one hour to studying. List those dates and times below. Record these in your agenda or phone.

   1.   2.   3.

Studying is most effective when it involves you *actively* using ideas and skills. Minimize the amount of *passive* studying you do, maximize the amount of *active* studying you do.

3. **Reason.** What are common "studying strategies" that do not encourage the active use of ideas and skills? These are *passive* forms of studying and probably shouldn't even be called studying.

4. **Reason.** The chart below describes the studying process that helps you to make best use of all the ideas presented in this lesson. Identify each step as active or passive. Determine how much time should be spent on each step (short or long).

The Studying Process

Step	Reason	Active or Passive?	Time
(1) **Review each lesson** in the unit or units. Identify the core ideas and basic skills.	Skills or ideas that aren't familiar probably need practice.		
(2) **Review your homework and quizzes**. Identify any ideas or skills you need to focus on.	Skills or ideas that caused you some trouble probably need practice.		
(3) **Find practice.** Find explanation questions to practice core ideas. Find many short questions to practice basic skills. Find longer, complex problems to practice applications.	Target your practice on exactly what you need. Don't waste time practicing things you are already good at.		
(4) **Practice.** Complete the practice questions under test-like conditions (no help, no distractions, with a time limit). Check your results.	The more closely you simulate the test situation, the better you will prepare yourself for the *experience* of the test.		
(5) **Evaluate and Repeat.** Based on the results of your practice, determine what else you need to focus on. Return to previous steps of the studying process.	When you do practice questions in test-like conditions you often discover what you really know and don't know.		

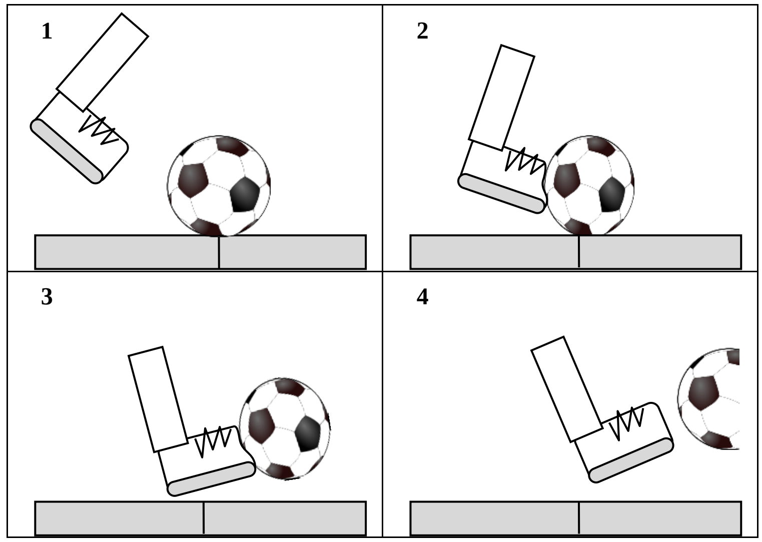
SPH3U: Interactions and Forces

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

When two objects affect one another in some way we say that they *interact*. Today we begin exploring the nature of these interactions and what happens as a result.

A: Thinking About Interactions

Watch the slow motion video of the foot kicking the ball. Refer to the frame numbers in the sketches to help answer the questions.



1. **Observe.** There is an interaction between the foot and the ball. In which frames is the interaction present?

2. **Observe.** What evidence is there (what do we <u>see</u>) that leads us to believe than the ball experiences an interaction? What about the foot?

The ball and foot interaction is an example of a *contact interaction*. Such an interaction is only noticeable when the two objects are in contact. When they are not in contact, there is no interaction.

3. **Reason.** Does the ball participate in any other contact interactions? In which frames and between which objects?

Non-contact interactions can take place even when the objects are not in contact: when the objects are separated by some distance, they still have an effect on one another. Note that an interaction always involves a **pair** of objects.

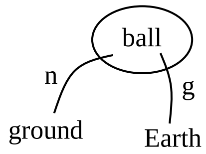
For the purpose of understanding interactions, we will think of and describe the ground and Earth as two separate objects since they often participate in interactions in different ways.

4. **Reason.** Does Earth participate in a non-contact interaction with the ball? Explain.

5. **Reason.** Does the ground participate in a *non-contact* interaction with the ball? Explain.

We can construct an *interaction diagram* (ID) to help represent the interactions present at some moment in time. An ID lists all the objects that are interacting with one another and has lines representing each interaction. The lines are labelled with a single letter describing the type of interaction: a = applied (a person's contact), g = gravitational, n = normal (surfaces in contact) and many more! There can be many, many interactions in a given situation so we need to narrow our focus by selecting a *system*: an object or collection of objects whose interactions we are interested in. We show the system objects by drawing a circle around them. We will usually leave out other interactions that don't involve the system objects.

6. **Represent.** In the chart below, complete the interaction diagrams for each of the four frames of the video. The ball is the system.

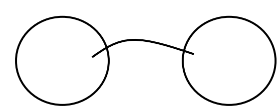
1	2	3	4
			

B: A Model Interaction

We are going to use an elastic band to examine an elastic interaction. **Each member** of your group should try this.

1. **Describe.** Loop one elastic band around your two pointer fingers. Separate your fingers until the elastic band has a good amount of stretch. Describe the effect the elastic has on **each** finger.

2. **Represent.** How does the pull of the elastic on each finger compare? Draw an arrow representing the force the elastic exerts on each finger. The arrow should **start** from each finger on the diagram. (Don't draw the elastic.)



Every interaction has two parts called *forces*. Intuitively, a force is a push or a pull of one object on another. In our previous example, we say the two fingers are interacting with one another through the elastic. The fingers pull on **each other**.

3. **Describe and Represent.** Rest your fingers and try again using the same elastic stretched to a **greater** distance than before. Describe how the sensation of force on your fingers has changed. Draw arrows again and explain how you chose to draw their **length**.

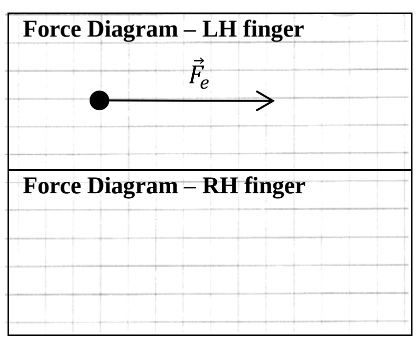
4. **Reason.** What type of quantity best represents a force: a scalar or a vector? Explain.

C: Representing Forces

We use a *force diagram* to model a system and represent the forces that the system experiences. In high school physics, we will always use the *point particle* assumption and imagine all the mass of the system objects compressed into a single point. For each interaction the system experiences, we draw a force vectors arrow that begins on the point particle. Label force vectors using a subscript showing the type of interaction (for example $\vec{F}_e$, an elastic force). Note that the arrow over top the force symbol does not show a direction, it just means "this is a vector".

1. **Reason.** Focus on the system of the left finger. According to the interaction diagram above, how many interactions does this finger experience? How many vector arrows should we draw on the force diagram?

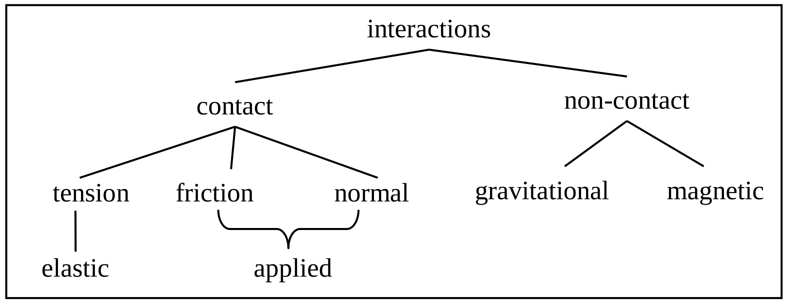
2. **Represent.** Now draw a force diagram for the system of the right hand finger hand. Explain how you choose to draw the length and direction of the force vector.



SPH3U Homework: Interactions Name:

A: Interactions and Forces

There are many different ways in which objects can interact and these different types of interactions can be organized into two large groups. Some common ones are listed below.

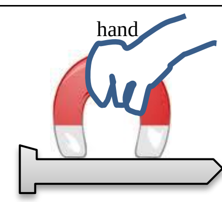
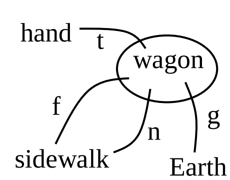


__Types of Interactions / Forces__

Tension (t) = two objects pulling on each other through a rope or string (no stretching)
Elastic (e) = two objects push/pull on each other due to stretch or compression of material
Friction (f) = resistance between two surfaces that are slipping or trying to slip past each other
Normal (n) = two surfaces in contact and pressing in to each other
Applied (a) = the contact force due to a person – a combination of friction and normal forces
Gravitational (g) = the gravitational interaction between two objects
Magnetic (m) = the magnetic interaction between two objects

Our contact interactions usually focus on solid objects. It is also possible to have a contact interaction with a fluid. One example of this is **air resistance** (a) or (air), and **buoyancy** (b) the interaction responsible for floating.

1. **Represent.** For each situation below complete the missing parts: the description (with the system), the sketch, or the interaction diagram.

Situation 1	Situation 2	Situation 3	Situation 4
A ball is attached to a string. Your hand holds the string steady. The ball does not move. system = ball	system = chocolate	system = nail	system =
			
			

2. **Reason.** In situation #1 above, your described the interactions for a ball and hand. To simplify our models, we often think of tension as an interaction between the two objects (hand and ball) that happens *through* the string. As a result, we won't show the string as a separate object in our interaction diagrams. If necessary, draw a new interaction diagram here to show this understanding of tension.

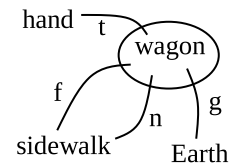
3. **Represent.** Draw a force diagram for situation #1 above. This is new for us, so just do your best to describe how you choose to draw the force vectors.

FD

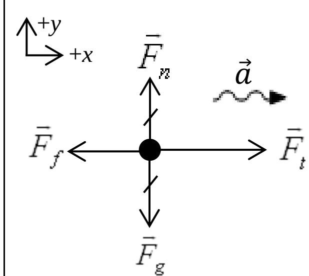
SPH3U: Forces Unit Rubrics

Use these rubrics to help assess the quality of your representations.

Interaction Diagrams

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Interaction diagram is constructed but contains many errors or a major error: • Missing or extra interactions (for the appropriate interval of time) • Missing or extra objects (for the appropriate interval of time)	Interaction diagram contains no major errors, but might have a few minor errors.	• The diagram contains all appropriate interactions and only the interacting objects. • System objects are enclosed in a shape (circle) • Each interaction is shown by one line (without arrows) connecting specific objects in the system or environment • Each interaction is labeled with a single letter (not a force symbol) • Each object's name is written only once	

Force Diagrams

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Force diagram is constructed but contains many errors or a major error: • Missing or extra forces (not matching with the interaction diagram) • Incorrect directions of arrows or incorrect relative length of force arrows.	Force diagram contains no major errors, but might have a few minor errors.	• The diagram is large, clear and has a coordinate system • It contains all appropriate forces and matches the interaction diagram. • Each force is labeled with a unique symbol that has a vector arrow. • 3rd law force notation ($F_{g\ e\text{-}b}$) is used if there are multiple systems or similar forces • Relative lengths of force arrows are correct, equal sized forces are shown with a "tick" mark. • Acceleration vector is drawn if appropriate.	

Newton's 2nd Law Expressions

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Expressions for Newton's 2nd Law are constructed but contain many errors or a major error: • missing or extra forces (not matching with the force diagram) • *x*- and *y*- forces are appear in wrong equation • one equation contains forces from both *x*- and *y*- directions	Force diagram contains no major errors, but might have a few minor errors.	• The process begins by writing the original 2nd law equation for each direction that has forces (i.e. $F_{net\ x} = ma_x$) • Each force is written with a unique force symbol and does not have a vector arrow symbol. • 3rd law force notation ($F_{g\ e\text{-}b}$) is used if there are multiple systems / similar forces • Direction of the force is shown using the sign convention. • If there is no acceleration, the equation equals zero.	$F_{net\ x} = ma_x$ $F_t - F_f = ma_x$ $F_{net\ y} = ma_y$ $F_n - F_g = 0$

Adapted from E. Etkina, *ISLE Laboratory Program*, https://sites.google.com/site/scientificabilities/rubrics

SPH3U: What is the Effect of a Force?

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

What happens when a single force acts on an object? This is a tricky question that took very clever people about 2000 years to figure out. Now it's your turn!

A: The Steady Pull

You need a dynamics cart and a 5-N spring scale.

We will use a spring scale to measure the size of forces. First you need to *calibrate* the spring scale. Hold the scale horizontally or vertically just as you will use it when measuring, but without pulling on it. Adjust the scale (a sliding cover or nut at the top) so it reads zero. The scale reads in units called *newtons* whose symbol is *N*.

1. **Test.** Practice exerting a **constant**, **horizontal** force (try around 1 N) on the dynamics cart. You should be able to do this for an interval of about four seconds. Practice this. When you are ready, call your teacher to witness your awesome technique.

2. **Reason.** To achieve a constant force, what must you observe about your spring scale?

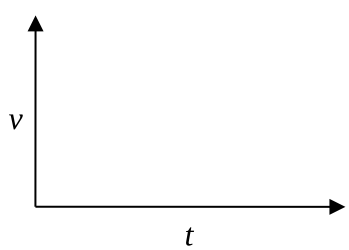
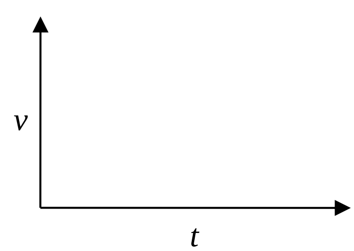
3. **Reason**. How does the cart move while it experiences the constant force? What are two possible guesses? Based on your observations, can you easily decide which guess might be correct?

B: On the Right Track

Your teacher has a cart set up on a track with a motion detector. Soon you will pull on the cart with a constant 1-N force.

A *hypothesis* is an idea that attempts to explain how something works. Once we have a hypothesis, we can use it to make a *prediction* about what might happen in a specific situation. A good prediction is detailed enough that we can use an experiment to test it. If the test shows that the prediction is not successful, the hypothesis is *refuted*. If the prediction is successful, our hypothesis is *supported* (it is strengthened and not yet refuted). We can never prove a hypothesis to be true!

1. **Predict.** People tend to have two hypotheses for this situation. Use each hypothesis to predict what the velocity graph for the cart should look like when the cart is pulled by a constant force.

Hypothesis A: When we exert a single, horizontal force on an object, it will move with a constant velocity.	**Hypothesis B**: When an object experiences a single, horizontal force, it will accelerate.
Prediction A 	**Prediction B** 

2. **Test and Evaluate.** Be sure to keep your force constant for as long as you can. Use the motion detector to track the cart's motion while you pull. Do your measurements support or refute the two hypotheses?

3. **Represent and Reason.** Draw an interaction diagram for the system of the cart while you exerted a constant force on it. Which of these interactions has a force that acts in the horizontal direction? Today, we are focusing on the horizontal forces acting our objects.

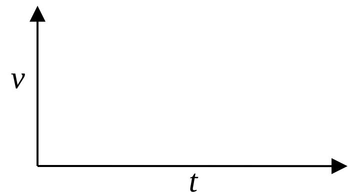
ID

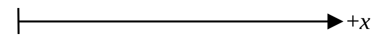
4. **Apply.** Isaac is in a store, pushing a shopping cart along the aisle. He says, "Look, I'm exerting a single force on the shopping cart and it is moving with a constant velocity. This contradicts the result I saw in physics class." Explain to Isaac how he should refine his thinking to understand what is happening in that situation.

C: Release the Cart!

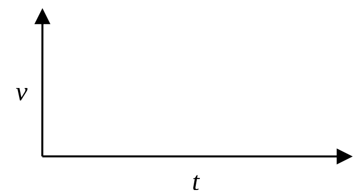
Pull the cart along the floor and then release it.

1. **Observe and Represent.** Complete the velocity graph and motion diagram for your cart. Label two events on each: (1) you release the cart, and (2) the cart stops.

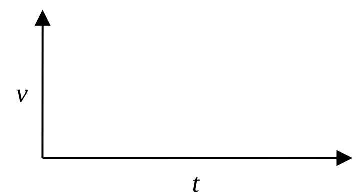




2. **Reason and Represent.** Imagine a new model: we change the cart and floor to reduce friction a bit. Explain how the motion of the cart after it is released would be different from the previous example. Sketch a velocity graph for this imaginary situation and explain how it appears different from the previous velocity graph.



3. **Predict and Represent.** Now imagine very special model: we carefully remove **all** sources of friction. After we release the cart, what would we observe in this very special situation? Sketch a velocity graph. In this situation what horizontal forces are acting on the cart?



4. **Observe.** (*as a class*) Describe the motion of the hover puck after it is released and is not pushed.

5. **Test.** (*as a class*) The hover puck is given a gentle push. Describe the motion of the hover puck *after* it is released.

D: The State of Things

In physics we use the term *state* to describe a category of motion or force. We have explored three seemingly different states of motion so far in grade 11 physics: (1) rest, (2) constant velocity, and (3) acceleration. We have just explored two seemingly different states of forces: (1) a single constant force, and (2) no forces at all. In science we look for patterns and sometimes these patterns reveal connections between things we thought were totally unrelated.

1. **Reason.** Use today's observations to describe the state of force that corresponds to each state of motion listed below. This will start our catalogue of force-motion relationships.

State of Motion	**State of Force**
Constant velocity	
Acceleration	
Rest	

2. **Reason.** Do you see any similarities between states that appear to be unrelated?

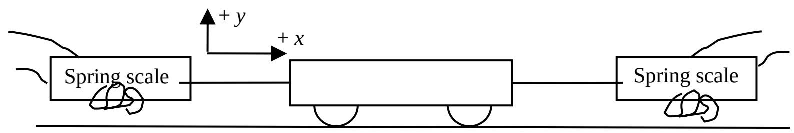
SPH3U: The Force-Motion Catalogue

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

Let's continue to explore the connection between different states of force and motion. You will need: a dynamics cart and two identical spring scales (5 or 10 N). Throughout this activity we make an important assumption: the forces of friction are very small compared to the other forces involved, so we will consider **the size of the force of friction to equal zero.**

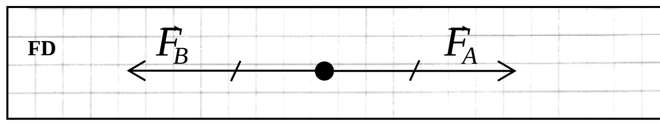
A: Two Forces

Calibrate your spring scales. Exert two equal-sized forces on the cart, but in opposite directions.



1. **Observe.** Describe the motion of the cart. Record the size of the forces.

2. **Interpret.** The force diagram (FD) to the right shows a model for the two tension forces you exerted on the cart. What do the "tick marks" and the lengths of these vectors tell us about the two forces?



The *net force* (F_{net}) is the combined effect of all the forces acting on an object or system. Since there may be forces in more than one direction (horizontal and vertical) we will often describe the forces and the net force in a particular direction ($F_{net\,x}$ or $F_{net\,y}$).

3. **Reason.** Without doing any math, what do you think the net force experienced by the cart in the *x*-direction is equal to?

To calculate the net force we will write a *component equation* using a sign convention to show directions. Forces acting in the positive direction are labelled positive and forces acting in the negative direction are labelled negative. **The values of the force symbols are all positive**. For example, if there is a single 10 N force $\vec{F}_A$ in the negative-*x* direction, we will write: $F_{net\,x} = -F_A$, where $F_A = 10$ N.

4. **Explain.** Below is the expression for the net force in the *x*-direction experienced by the cart. What do the + and – in this equation tell us about the two forces?

$$F_{net\,x} = +F_A - F_B$$

5. **Calculate.** You measured the size of the two forces acting on the cart. Substitute those values into the net force expression and find the result.

In the future, if the first symbol in the expression for the net force is positive, we won't write the positive sign. If the net force equals zero we say that the forces acting on the object are *balanced*. In part A, the forces acting on the object in the *x*-direction are balanced.

6. **Summarize.** What is the state of motion of an object that experiences balanced forces?

B: On the Move

What will happen to a cart that is already moving if it experiences balanced forces? Refer to the cart your teacher has set up at the front of the room.

1. **Represent.** Draw a FD for the cart your teacher has set up. Label the two forces. Note that the strings attached to the weights are pulling on the cart horizontally. $F_A = 5$ N and $F_B = 5$ N.

FD

2. **Calculate.** Write an expression for the net force in the *x*-direction and calculate the result.

3. **Predict.** Your teacher will start the cart moving and then let go. Once released, the only horizontal forces acting on the cart will be the two tension forces. Think back to the conclusions we reached last class: even though the chart doesn't cover this situation, is there one state that seems "close" to this? Predict the state of motion of the cart after it is let go.

4. **Test.** (*as a class)* Describe your observations. Do they confirm your prediction? Explain.

C: Net Force is Not Zero

Now we make a small change to the cart set up at the front: we increase the size of one of the forces. $F_A = 6$ N.

1. **Represent.** Draw a FD and label the two forces. How should you draw the length of the two force vectors?

2. **Calculate.** Write an expression for the net force and calculate the result.

FD

The net force (F_{net}) is our only force quantity that can have a negative value. We interpret this to mean the net force points in the negative direction. If the net force is not equal to zero, we say that the forces acting on the object are *unbalanced*.

3. **Predict.** Again, look back to the chart from last class. Is there a state that is "close" to this one? Use this to predict the state of motion for this situation, after the cart is released.

4. **Test.** (*as a class)* Describe your observations. Do they confirm your prediction? Explain.

If a system accelerates, draw a separate wiggly acceleration vector (a) alongside the force diagram.

5. **Speculate.** According to your calculation for the net force, what single force could replace the two forces in this situation? Draw a FD for this situation.

FD

6. **Test.** (*as a class)* The cart now experiences a single force equal to the net force from before. How does the acceleration of the cart compare with your previous observations?

The net force gives us the combined effect of all the forces acting on an object. The object behaves just as if a single force was acting on it that had the same magnitude and direction as the net force. Judging from only the motion of the object, we cannot tell the difference. We will call this idea the *net force principle*.

D: Three Forces!

It is now time to return to your dynamics cart. Your challenge is to create a situation where three forces act in the *x*-direction and are balanced. Get a third spring scale and try this now.

1. **Reason and Represent.** Decide how you will attach the spring scales and draw a FD. When we have multiple forces in one direction, draw the vectors *tip to tail* (in one row, not overlapping). Label the forces.

FD

2. **Calculate.** Write an expression for the net force and use your values to calculate the result.

3. **Reason.** Even if you couldn't see the readings on the spring scales, why do you believe you successfully balanced the three forces acting on the cart?

E: The Forces-Motion Catalogue

Complete the chart below showing the correspondence between all the different states of force and motion we have explored.

State of Force	**Net Force** (circle one)	**State of Motion**
No forces at all	zero / non-zero	1)
		2)
Balanced forces (two or more)	zero / non-zero	1)
		2)
One single, unbalanced force	zero / non-zero	
Unbalanced forces (two or more)	zero / non-zero	

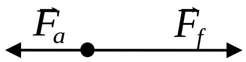
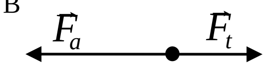
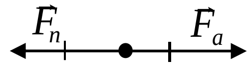
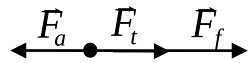
1. **Reason.** People get very excited when things that seem different are actually very similar. We have four different states of force in our chart. Can we reduce the number of states? If so, how should we label the new states of force?

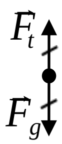
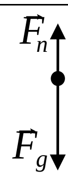
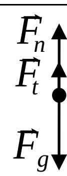
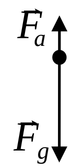
2. **Reason.** According to the chart, can we use information about forces or the state of force to decide if an object is at rest or if it is moving with a constant velocity?

Newton's First Law

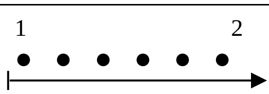
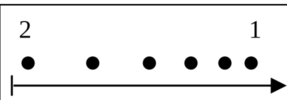
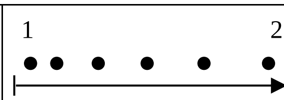
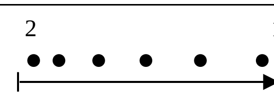
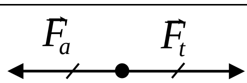
SPH3U: The Net Force Homework Name:

1. For each force diagram, decide on the state of force. Add a wiggly acceleration vector  to the force diagram, if appropriate. Write the expression for the net force in the *x- or y*-direction. Use the directions right or up as positive. What state of motion will be the result: acceleration or rest/constant velocity? Look at the sample answers for hints on what to do if you're stuck.

FD	A 	B 	C 	D 
State of Forces		unbalanced		
$F_{net\ x}$	$= F_f – F_a$			
State of motion				acceleration

FD	E 	F 	G 	H 
State of Forces	balanced			
$F_{net\ y}$		$= F_n - F_g$		
State of motion				acceleration

2. Two forces act in opposite directions on an object, F_t to the right and F_a to the left. Describe the state of motion. Compare the size of the two forces. Draw a force diagram. Include a wiggly acceleration vector when appropriate.

Motion Diagram				
State of Motion				
Compare		$F_t < F_a$		
Force Diagram				

3. You pull a wagon horizontally along the rough ground. The wagon is speeding up. Complete the chart below. Use your understanding of the states of motion and force in each direction to help you draw the force diagram.

Interaction Diagram	Vertical Direction	Horizontal Direction	Force Diagram
	State of motion: State of forces:	State of motion: State of forces:	

SPH3U: The Change of Force Principle

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

We have made a great discovery with Newton's First Law (our catalogue of force-motion relationships). Now we need to figure out what happens when forces change.

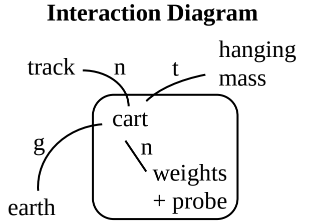
A: Systems and Interactions

Your teacher has a cart set up on a track with a motion detector and a force sensor. We will create a model for the system of the cart including the extra weights and probe. Our experiment has three events: (1) the cart is released from rest with the hanging mass pulling on it, (2) the mass hits the ground, and (3) the cart reaches the end of the track.

1. **Reason** (*as a class*)**.** Observe the cart moving along the track without the hanging mass pulling. What assumptions should we include in our model?

Objects outside the system are in the *environment*. Force diagrams only show *external forces*, which are forces from interactions between system objects and the objects in the environment. FDs do not show *internal* forces, forces from interactions between two system objects.

2. **Represent.** We will begin by focusing on the system between events 1 and 2. Complete the chart below. Use the interaction diagram to determine the number of force vectors to draw. Use your understanding of the state of motion and force in each direction to determine the size of the force vectors.

Interaction Diagram	**Vertical Direction**	**Horizontal Direction**	**Force Diagram**
	State of motion: State of force:	State of motion: State of force:	

3. **Record.** Draw your FD on your whiteboard to share with the class.

B: Change of State

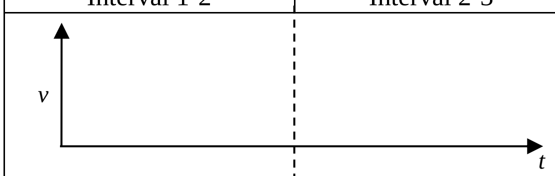
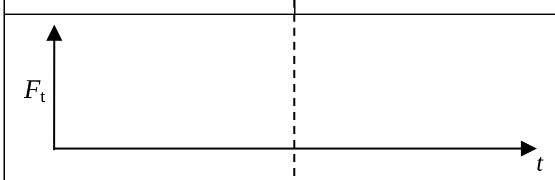
Let's return to our experiment. We are interested in exploring what happens to the state of motion when forces suddenly change.

1. **Observe and Interpret.** (*as a class)* Observe the results from the computer. Complete the velocity and tension force graphs. Label the events. Complete the rest of the chart.

2. **Interpret.** During this experiment the state of motion changes and the state of the forces change. What do you notice about the timing of these two changes?

When the net force experienced by a system changes, the acceleration changes at the same time. There is no delay between one and the other – the changes are simultaneous. We will call this idea the *change of force principle*. This is an important part of Newton's First Law.

3. **Reason.** Isaac says, "When the counterweight stops pulling on the cart, I don't understand **why** the cart moves with a constant velocity. I think we should draw a forwards force on the FD for interval 2-3." Do you agree or disagree with Isaac? Explain.

Interval 1-2	Interval 2-3
	
State of Motion:	State of Motion:
	
State of Forces:	State of Forces:
FD	FD

C: Throw in the Towel

Now we will repeat this experiment with just one change – a piece of paper towel is taped underneath the cart such that it rubs on the track as the cart moves.

1. **Predict**. There are three common hypotheses to explain what happens in this situation.

    Hypothesis A: After the force of tension stops the cart moves for a while, and later friction starts to slow it down.

    Hypothesis B: When the force of tension stops, the cart *immediately* stops due to the force of friction.

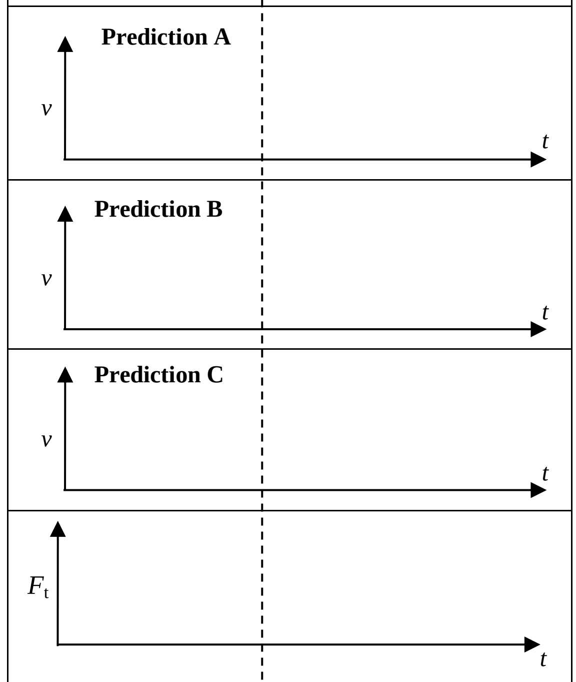
    Hypothesis C: When the force of tension stops, the state of motion changes right away to a new acceleration.

    Use each hypothesis to predict a velocity graph for the cart. Draw each prediction in the chart.

2. **Test and Evaluate.** (*as a class*) Use the computer results to test the predictions. Evaluate which hypothesis is supported and which is refuted.

3. **Represent.** Complete the chart. Draw a FD for the cart during each interval. Write an expression for the net force in the *x*- and *y*-directions.

Interval 1-2	Interval 2-3



FD	FD
$F_{net\ x}$ =	$F_{net\ x}$ =
$F_{net\ y}$ =	$F_{net\ y}$ =

All ordinary matter has a property called *inertia*. When forces are unbalanced, it takes **time** for the velocity of an object to change. In some cases the time interval for the change can be very small, but it is **never** zero. We will call this idea the *inertia principle*. The amount of time is related to the size of the net force and the amount of inertia (the mass). This is a first hint at another law of physics!

4. **Reason.** Albert says, "I'm pretty sure that when I push a heavy box along the floor and let go, its state of motion changes suddenly from constant velocity to rest." Do you agree with Albert? Explain why he might have this understanding.

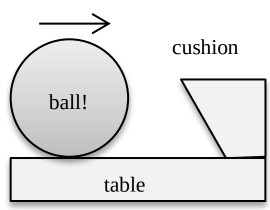
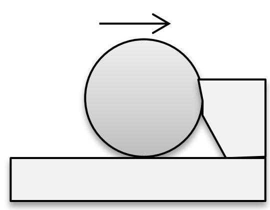
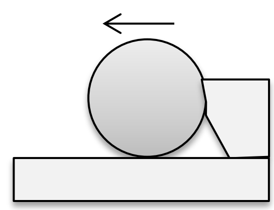
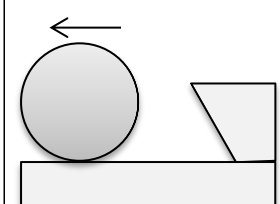
SPH3U Homework: The Force-Change Principle Name:

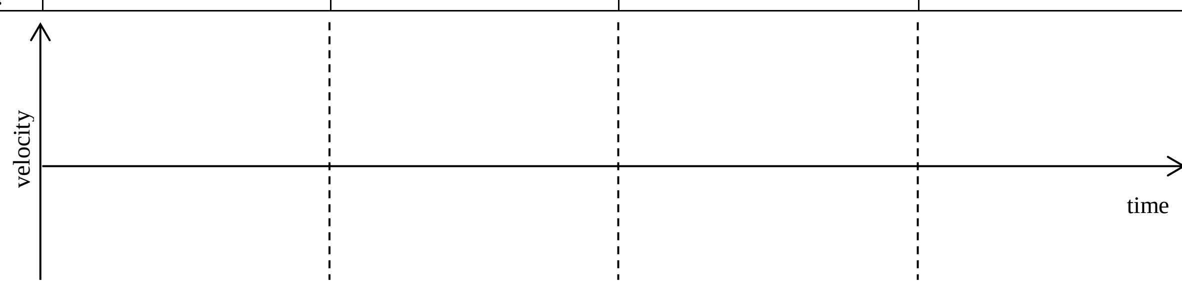
A: The Billiards Game

In the game of billiards (sometimes known as "pool"), a ball bounces off the cushion at the side of a table. Friction between the ball and the table surface is very small compared with other forces, so make an assumption in your model. We choose five events to help us explore what happens:

(1) The ball is travelling towards the cushion.
(2) The ball makes contact with the cushion.
(3) The cushion is squished and the ball stops.
(4) The ball leaves contact with the cushion.
(5) The ball is travelling away from the cushion.

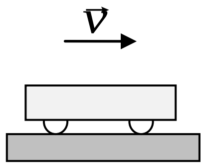
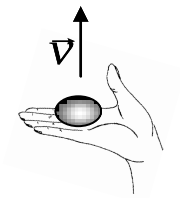
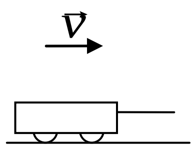
1. **Reason and Represent.** For each interval of time between the pairs of events:
   (a) Draw an interaction diagram and a force diagram. The possible interacting objects are ball, Earth, table and cushion. Label the normal forces $F_{n\ c\text{-}b}$ (normal force of cushion on ball) and $F_{n\ t\text{-}b}$ (normal force of table on ball)
   (b) Describe the state of forces, the state of motion, and what is happening to the speed.
   (c) Sketch a velocity time graph and label the events (the graph is divided up according to the time intervals).

Interval	1-2	2-3	3-4	4-5
Description	Ball rolls towards cushion	Cushion becomes squished (compressed)	Cushion expands	Ball rolls away from cushion
Sketch				
Interaction Diagram				
Force Diagram				
State of Forces				
State of Motion				
Speeding Up or Slowing Down?				
Velocity Graph				



SPH3U: Force of Gravity Homework

1. **Represent.** Complete the chart for each situation described.

	Description	Sketch	Interaction Diagram	Force Diagram	Net Force
1	A cart glides along a table with no friction. System = cart				$F_{net\,x}$ = $F_{net\,y}$ =
2	A tasty chocolate in your hand is moving upwards with a constant speed. System = chocolate				
3	You lower a ball using a string. It *slows down*. System = ball				
4	You pull along the horizontal handle of a wagon. It travels along the rough ground and speeds up. System = wagon				

2. **Calculate.** The chocolate in situation #2 has a mass of 20 g. We want to find the size of the upwards force you exert on the chocolate. Albert is having difficulty with this. Explain to him what happens in each step of the work presented to the right.

	$F_{net\,y} = F_a - F_g = 0$
	$\therefore F_a = F_g$
	$\therefore F_a = mg$
	= (0.020 kg)(9.8 N/kg)
	= 1.96 N
	The upwards force has a size of 1.96 N

3. **Calculate.** The dumbbell in situation #3 has a mass of 10 kg and you pull upwards with a force of 15 N. What is the size of the normal force?

4. **Calculate.** The wagon in situation #4 experiences a net force of 30 N and a force of friction of 10 N. What is the size of the pulling force?

Answers: (3) 88 N, (4) 40 N

SPH3U: The Force of Gravity!

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

How does an object's mass affect the size of the force of gravity it experiences? Let's find out. You will need: one 10-N spring scale, a hanging mass, a variety of masses, and some gravity.

A force that is noticeable only when two objects are in contact, is a *contact force*. Any force that has a noticeable effect even when the objects are separated is called a *non-contact force*.

1. **Reason.** Is gravity a contact force or a non-contact force? How can we tell?

2. **Represent.** Draw an ID and a FD for the hanging mass. Explain why we can use the scale reading (an upwards force of tension) to determine the size of the force of gravity.

ID	FD

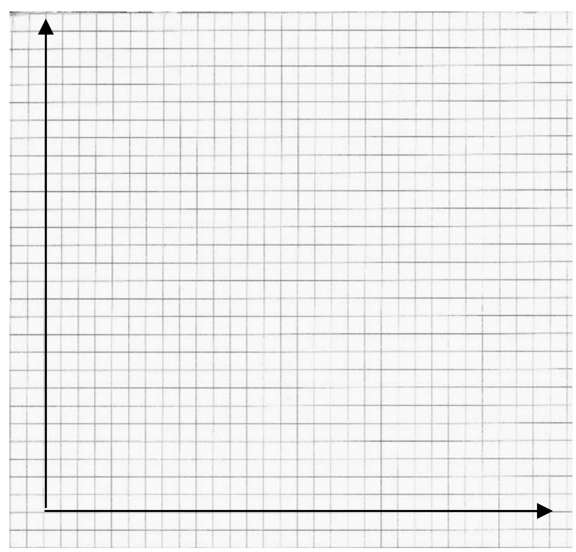
3. **Design.** We want to find out how the magnitude of the force of gravity depends on the mass of the object. Describe how you will conduct a simple experiment to collect data and determine this.

4. **Observe.** Record your data in the chart.

5. **Analyze.** Decide which variable is the dependent one. Plot your data on the graph. Use the shape of the graph to describe how the force depends on the mass.

6. **Calculate.** Determine the slope of your graph, including units. Show your work on the graph.

Mass, m (kg)	Force of Gravity, F_g (N)
0	



The slope of your graph gives a very important quantity, the *local gravitational field strength* $\vec{g}$. It tells us how much force the earth's gravity exerts on each kilogram of matter in an object at this location. The exact value depends on many factors including geographic location, altitude, and planet. The accepted value for your location is: _______ N/kg [down].

7. **Analyze.** Write an equation for your line of best fit. Be sure to write "$y = mx+b$" using physics symbols.

8. **Apply.** Use your new equation to determine the size of the force of gravity acting on a 1.5×10^3 kg car.

SPH3U: Normal Forces Homework   Name:

You grab your physics textbook off a shelf and lower it down on to your desk in preparation for doing your homework. (What a good student you are!) As the book moves, it lies flat on the palm of your hand. Let's take a look at the physics of this **daily** routine. There are four important events that take place: (1) The book begins to speed up as it starts moving downwards, (2) the book reaches a constant velocity, (3) the book begins to slow down as it nears the desk, and (4) the book comes to rest at the bottom.

ID

1. **Represent.** Draw an interaction diagram for the system of the book during this sequence of events.

2. **Represent.** Complete the chart below for each of the three intervals in the book's downwards motion.

3. **Explain.** Which force changes during this sequence of events? How does that affect the book's motion?

4. **Calculate.** The mass of the book is 1.3 kg. What is the size of the force exerted by your hand between events 2 and 3?

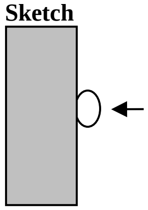
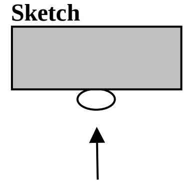
5. **Test and Describe.** Try this. Find a heavy book and place it on the palm of your hand just like in the picture. Lower the book just as we have described above. Try to connect how it feels in your hand when you do this with your understanding of the forces. Describe what you notice.

Interval	1-2	2-3	3-4
Motion Diagram	↓ +*y*	↓ +*y*	↓ +*y*
Force Diagram	•	•	•
Net Force	=	=	=

5. **Reason.** Your friend places the same book on a table. She then leans on top of it, pushing down with 7 N of force. Draw a FD for book with and without the downwards push. Compare the size of all the forces in the two diagrams.

FD – no push	FD –push
•	•

6. **Represent.** You throw a very bouncy ball which hits a wall and then the ceiling. Draw an ID and a FD for the ball while it is (a) in contact with the wall and (b) in contact with the ceiling. Hint: the direction of the acceleration vector is tricky – just make a guess based on the FD.

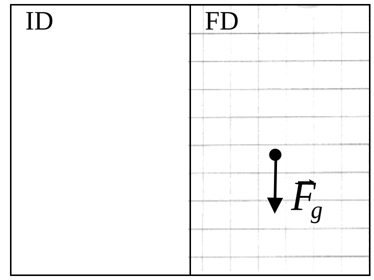
Sketch	ID	FD	Sketch	ID	FD
					

SPH3U: The Normal Force

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

A: A Mysterious Force

Your friend places her backpack on a table. The backpack is the system.



1. **Reason.** Your friend draws a FD for the system and says, "I'm really not sure that there should be an upwards force." Convince your friend. Cite direct evidence about the system that you can readily observe.

2. **Reason.** Complete her original FD and draw an ID. The backpack has a mass of 5.8 kg (all those textbooks). What is the size of the upwards force?

When two objects press against one another, they interact and exert *normal forces* on one another. A normal force (F_n) is a contact force that is always perpendicular to the surfaces at the point of contact. This force usually prevents objects from deforming by much, from breaking or from merging together. When a person is in contact with another object, we call this special normal force an *applied force*. Note that an applied force can also be a combination of a normal force and a friction force (which we will study later).

B: Evidence for the Normal Force

For these activities you need two metre sticks, a spring scale and a 500 g mass. Make a bridge using the metre stick between two tables. Gently press downwards with your finger in the middle of the metre stick.

1. **Observe.** Describe what you observe happening to the "rigid" metre stick. Why did the shape change?

2. **Reason.** Describe the evidence you feel for the existence of an upwards force acting on your finger.

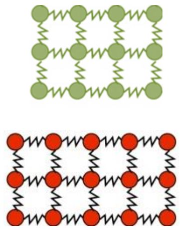
3. **Observe.** Place the 500 g mass on the metre stick. Describe what happens. What is the size of the upwards normal force?

4. **Observe.** Remove the mass. Place the second metre stick directly on top of the first (the "table" is now twice as thick). Place the 500 g mass on top of the two sticks. What is different about the effect of the mass on our thicker "table"? How has the upwards normal force changed? Explain.

*** Check with your teacher before proceeding. ***

5. **Reason.** Imagine many, many metre sticks stacked up (a very thick table). What would happen to the metre sticks if we place the 500 g mass on top of them? How has the size of the upwards normal force changed compared to the single metre stick situation? Explain.

6. **Explain.** (*as a class*) How does the normal force work on a microscopic level?

A Physical Model for the Normal Force	Particles Before Contact 	Particles After Contact

C: Measuring the Normal Force

You need a 0.5-kg mass and a 5 N spring scale. Place the mass on the table.

1. **Reason.** What is the size of the upwards normal force on the mass? Explain.

2. **Analyze and Predict.** In a moment you will pull upwards on the mass with a 3 N force.
   (a) Draw an ID and a FD for this situation.
   (b) What is the state of the forces? Write an expression for $F_{net\ y}$.

   (c) Predict the size of the normal force in this situation.

ID	**FD**

3. **Test.** Attach a spring scale to the mass and exert a 3 N force upwards. Try this with the mass on your hand. How did the sensation in your hand change?

4. **Test**. Place the mass on the force pad and exert the 3 N force upwards. Determine the size of the normal force. Does this result agree with your prediction? Explain.

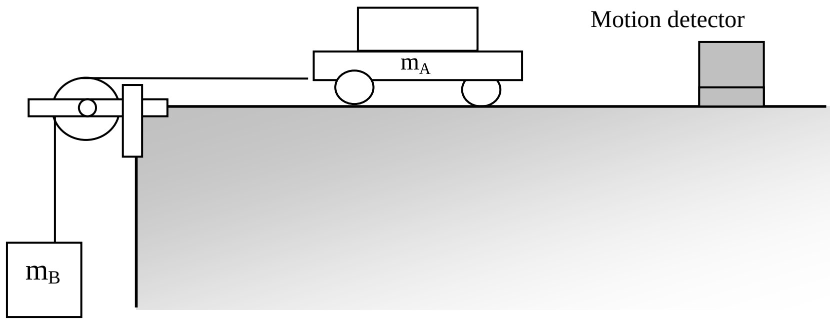
The magnitude of the normal force depends on how hard the objects are pressing against one another. Other forces and motion may affect the size of a normal force. As a result, we always have to find the size of the normal force by analyzing what's happening to the system.

SPH3U: Force, Mass and Acceleration

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

What factors affect the acceleration of an object? We have already hinted that force and mass are key. Today's investigation will help you understand how these quantities affect the acceleration.

Your group will use the carts and masses set up in the classroom. A motion detector will help track the velocity of the cart. Complete **all** the questions below before beginning the experiment and show this page to your teacher.



A: The Atwood Machine

1. **Reason.** Why does each mass, m_A and m_B, move when released. What forces cause the acceleration of each mass?

2. **Reason.** When the mass m_A is released how much mass is moving in total?

3. **Reason.** We can think of the two masses as a single system. What single force is the ultimate cause of the acceleration of the entire system (m_A and m_B together)? This is the force we will vary in our experiment.

4. **Reason.** To conduct a scientific investigation one must always change only one quantity and measure the results while ensuring that everything else remains unchanged. Suppose you want to increase the force moving the system while keeping everything else the same. You add 50 g to m_B. What else **must** you do?

B: Investigating the Effects of Force

In the first experiment you will vary the force while keeping all other properties constant, to determine the effect of the net force on the acceleration. The computer will produce a velocity-time graph for you to analyze.

1. **Design an Experiment.** Describe how you will conduct your experiment. Show your teacher when you are ready.

2. **Observe.** What is the total mass of your system ($m_A + m_B$)? Remember, you must keep this constant!

3. **Observe.** (*as a class*) Conduct the experiment and record your results in the chart below. Make fairly large changes in the masses (about 200 g). If m_B becomes too large the motion detector may have difficulty making measurements.

m_A (kg)	m_B (kg)	System Mass (kg)	Net Force (N)	Acceleration (m/s^2)

4. **Represent.** Construct a graph of your results with the **net force on the vertical axis**. We are choosing the axes this way to help with the interpretation of the slope at a later step. Draw a line of best fit.

5. **Interpret.** Use the pattern in your graph to help explain how acceleration depends on force.

6. **Calculate.** Determine the slope of the line of best fit. Show your work.

7. **Interpret.** Is the value of the slope close to any other quantities which describe our system? What do you think the slope physically represents about the object?

8. **Represent.** Write an equation for the line on your graph. Remember to use physics symbols!

9. **Reason.** If we double the force acting on the system (and keep the mass constant), what will happen to the acceleration?

10. **Reason.** If we reduce the force to one third (and keep the mass constant), what will happen to the acceleration?

C: The Effect of Mass on Acceleration

This is a quick investigation what will help us to determine how changing the mass of the system will affect the acceleration, when the net force remains constant.

1. **Design an Experiment.** We want to double the mass of the system and keep the net force constant. Choose your original values and changed values for m_A and m_B that will accomplish this. Keep in mind the actual mass of the cart as you do this.

Original	**Changed**
m_A :	m_A :
m_B :	m_B :
System mass:	System mass:
Net force:	Net force:

2. **Observe.** Use the Atwood machine and motion detector to conduct your investigation. Record your results below.

Original	**Changed**
System mass:	System mass:
Acceleration:	Acceleration :

3. **Find a Pattern.** Roughly speaking what happened to the value of the acceleration when you doubled the mass?

4. **Reason.** What do you think the acceleration would be if you were able to reduce the original system mass by half? Explain.

D: Conclusions

1. **Evaluate.** Earlier you created an equation that shows the relationship between the net force (F_{net}), the mass (m) and the acceleration (a) of a system. Does this equation include the two key results from your two experiments: acceleration depends on mass and acceleration depends on the net force? Use phrases like "if you double the ______ and _______ remains constant, the _________ doubles" to explain.

2. **Summarize.** (*as a class*)

Newton's Second Law

Newton's Second Law is the rule for our universe that describes the relation between cause (forces) and effects (acceleration).

3. **Apply.** We can use Newton's 2^{nd} Law to explain what 1 N of force is and find the hidden meaning of the unit newton (N).
   (a) Use the equation for the 2^{nd} law to find the net force experienced by a 1.0 kg mass that accelerates at 1.0 m/s^2.

   (b) Your result shows the fundamental units that the newton (N) is equivalent to. As a result, the symbol N is short form for what basic units?

SPH3U: Force, Mass and Acceleration Homework Name:

Newton's Second Law ($F_{net} = ma$) is the rule for our universe that describes the relation between cause (forces) and effects (acceleration).

A: The Units of Force

1. **Represent and Explain.** A 3 kg rock is falling to the ground.
   (a) Draw an ID and FD.
   (b) Determine the size for the force of gravity acting on the rock.

ID	FD

   (c) Use Newton's second law to find the acceleration of the rock while it is falling. Explain why the units of the calculation work out to give an acceleration. (Hint: You can replace the symbol N with what other units?)

B: Find the Missing Force

1. You pull your friend on a wagon using a horizontal, forwards force. There is a small amount of friction. The wagon is gradually speeding up.
   (a) **Represent.** Draw an ID and a FD for the system of wagon + friend.

ID	FD

   (b) **Reason.** Which horizontal force is larger? Explain.

   (c) **Represent.** Complete the expressions for the Newton's second law in the *x*- and *y*-directions. Use the symbols for the forces and a sign convention. If the acceleration in a direction is zero, substitute that in your expression.

$F_{net\,x} = ma_x$ $\quad\quad$ $F_{net\,y} = ma_y$

$=$ $\quad\quad\quad\quad\quad\quad$ $=$

   (d) **Reason.** The mass of your friend is 57 kg. The mass of the wagon is 12 kg. What is the mass of the system? What mass value will you substitute for *m* in your equation? Explain.

   (e) **Reason**. Your friend speeds up at a rate of 1.1 m/s^2. You pull with a force of 97 N. You are interested in finding the size of the force of friction. Which component equation for Newton's 2nd law will help you find F_f?

   (f) **Solve.** What is the size of the force of friction?

Answers: (1) 29.4 N, 9.8 m/s^2 downwards, (2) 21.1 N

SPH3U: Modelling Problems Using the 2nd Law

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

Newton's 2nd Law, $F_{net} = ma$, is the law of cause and effect: it relates the causes of motion (forces) with its effects (acceleration). As a result, any problem that involves both force and motion will likely use the 2nd law. To understand the force side of the equation we use force diagrams and calculate the net force. To understand the acceleration side we use motion diagrams and the BIG 5 equations.

A: The Cart and Hanging Mass

Today our goal is to create a model that will allow us to predict the velocity of a cart pulled by a hanging mass. Similar to the previous investigation, our **system is the cart plus hanging mass**.

1. **Reason.** All models depend on assumptions and are valid for certain time intervals. Describe your assumptions in part C and describe the events that start and end your time interval in part A.
2. **Measure.** You will need to know some information about your system. Examine the equipment and record the information in part A below. Your teacher will give you a value for the force of friction.
3. **Predict.** The purpose of this model is to predict the velocity of the cart 0.75 s after it is released. Complete the steps of the solution process below to determine your prediction.

A: Pictorial Representation

Sketch showing events, coordinate system, label givens & unknowns with symbols, conversions, describe events

B: Physics Representation

Interaction diagram (system = cart + hanging mass), force diagram

The force of gravity on the hanging mass causes the system to accelerate. Show this as a horizontal force F_{hm} on your FD.

C: Word Representation

Describe motion (no numbers), explain why, assumptions, estimation (no calculations)

Did you explain *why* it speeds up?
What are we assuming about this model?

D: Mathematical Representation

Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction.

What is the mass of the system?

E: Evaluation

Answer has reasonable size, direction and units? Explain why.

4. **Test.** You have made a prediction using your model. Test your prediction using the motion detector. Does the measurement agree with your prediction?

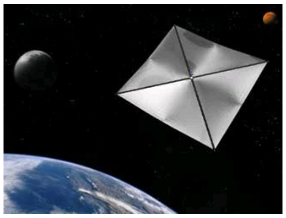
5. **Evaluate.** Scientists test models, evaluate their reliability, and search for ways to improve their models. You probably found that your prediction was close, but still noticeably different from the measured result. What accounts for this difference? Are there other sources of friction? If you wanted to build an improved model, what would you try to measure to add more information?

B: Sample Problems

Use a forces solution sheet for your solutions. Use the check list below to help improve the quality of your solutions.

- ☐ I described the events carefully. Sometimes the descriptions are very simple. (e.g. Event 2 = 1.5 s later)
- ☐ I used the forces unit rubric to check the quality of my IDs and FDs.
- ☐ I compared the size of forces to explain why the system is accelerating.
- ☐ I carefully described the physics of each step with clear, complete phrases. (I didn't write, for example, "find a")

1. The Elevator. An elevator and its load have a combined mass of 1600 kg. It is initially moving downwards at 3.2 m/s. When the elevator passes the second floor, a motor attached to the cable supporting the elevator causes it to slow down through a distance of 8.7 m, allowing the people to get out on the first floor. What is the size of the force of tension in the cable?



2. Sunjamming. A "sun yacht" is a spacecraft with a large sail that is pushed by the force of sunlight (F_L). Although such a push is tiny in everyday circumstances, it can be large enough to send the spacecraft outward from the Sun on a cost-free but slow trip. Your spacecraft has a mass of 900 kg and receives a steady push of 20 N from the sun. It starts its trip from rest. How far will it travel in 1.0 days and how fast will it then be moving?

3. Two People Pull. Two people are having a tug-of-war and pull on a 25 kg sled that starts at rest on frictionless ice. The forces suddenly change as one person tugs harder with a force of 92 N compared with the other person's force of 90 N. How quickly is the sled moving after 1.5 s?

4. Take Off. A Navy jet with a mass of 2.3×10^4 kg requires an airspeed of 85 m/s for liftoff. The engine develops a maximum force of 1.07×10^5 N, but that is insufficient for reaching takeoff speed in the 90 m runway available on an aircraft carrier. What minimum force is needed from the catapult that is used to help launch the jet?

Answers: (1) 16 600 N, (2) 8.29×10^7 m, 1.92×10^3 m/s, (3) 0.12 m/s, (4) 8.16×10^5 N

Adapted from Cummings, K., et al, *Understanding Physics*. Wiley, 2004

SPH3U: Exploring Freefall

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

A fascinating example of force and motion is that of falling objects. How does an object move when it is falling? Let's find out!

A: Drop the Ball!

There is a motion detector attached to the ceiling of the classroom. A student will hold a large ball of playdoh underneath the detector and release it (no downwards push). We will focus on what happens as it drops and lands on the ground.

1. **Observe.** (*as a class*) Sketch the results from the computer for the velocity graph of the ball. The graph might show a repeating pattern.

2. **Explain.** (*as a group*) Using a velocity graph, how can we decide when the acceleration is constant?

3. **Interpret.** We will choose to mark an event when the acceleration of the ball changes or its velocity is zero. Label the three events: (1) The ball is released, (2) the ball makes contact with the ground, and (3) the velocity of the ball is zero.

4. **Interpret.** For each interval of time between your events, decide whether the ball is speeding up (SU) or slowing down (SD). Label this on the graph.

5. **Represent.** There are two intervals of time between the three events we have chosen. For each interval of time, describe the states of motion and force. Draw an interaction diagram, and draw a force diagram.

Interval	1-2	2-3
State of Motion		
State of Forces		
Interaction Diagram		
Force Diagram		

In our model, *freefall* occurs whenever an object moves vertically under the influence of gravity alone. We assume that there are no forces other the force of gravity.

6. **Reason.** During which interval(s) of time did freefall occur? Explain here and label these regions above your chart and above your graph.

7. **Predict.** Use Newton's 2nd law to predict the size and direction of the ball's acceleration during freefall. (Hint: we don't know the mass of the ball, so just use the symbol *m*).

In our model, the acceleration value of a freefalling object, the *freefall acceleration* a_f, has a constant value of:

8. **Evaluate.** Use the computer data from the velocity graph for the ball drop to determine the acceleration. Does this agree with your prediction? What assumption might explain why your prediction is off by a small amount?

B: Analyzing the Motion of a Tossed Ball

A student will hold a ball underneath the detector, throw it straight up and down, and catch it. The student should begin and end the throwing motion with his or her hands low down.

1. **Observe.** (*as a class*) Sketch the results from the computer for the velocity graph of the ball.

2. **Interpret.** (*as a group*) There are five (!) important events that we would like to focus on. Label these on your velocity graph.
   (1) the hand begins to push the ball upwards
   (2) the ball leaves contact with the hand
   (3) the ball reaches its highest point
   (4) the ball makes contact with the hand
   (5) the ball stops

3. **Represent.** Complete the chart below.

Interval	1-2	2-3	3-4	4-5
State of Motion				
State of Forces				
Interaction Diagram				
Force Diagram				

4. **Reason.** Isaac says, "At its highest point, the acceleration of the ball is zero. We know that because it is turning around." Do you agree or disagree? Explain.

5. **Reason.** Emmy says, "At its highest point, the ball has a velocity of zero." Marie says, "I agree and at its highest point it remains at rest for a short interval of time." Who do you agree with? Explain.

6. **Reason.** At which event does freefall begin? At which event does it end? Explain.

7. **Reason.** The BIG 5 equations are valid (they will give reliable results) as long as the acceleration is constant.
   (a) Could you use a BIG 5 equation to make a calculation for the interval between events 3 and 5?

   (b) What about for the interval between events 2 and 4?

SPH3U Homework: Exploring Freefall   Name:

A: The Rising Ball

In class, a student threw a ball upwards underneath the motion detector. For this situation, we will use the same event numbers as we did in class.

1. **Represent.** Draw an interaction diagram and a force diagram for the ball during the intervals 1-2 and 2-3. Label the interval that is freefall.

Interval 1-2		Interval 2-3	
ID	FD	ID	FD

2. **Predict.** Based on our motion detector measurements in class, we observe that the ball leave contact with the hand with a velocity of 3.3 m/s upwards. Use our freefall model to predict how high the ball will travel above the student's hand. (Hint: what is the speed of the ball at event 3?)

3. **Evaluate.** According to the position measurements of the motion detector, the ball traveled 61 cm above the hand. How does your height prediction compare with the data collected from the computer?

4. **Evaluate.** Is the actual acceleration larger or smaller than in our model? (Look back at the investigation) Can that explain the difference between your prediction and the measured result?

5. **Calculate.** The student moved the ball upwards during interval 1-2 by pushing upwards on the ball for a distance of about 40 cm. What is the size and direction of the acceleration of the ball while it was in contact with the hand? (Hint: we know two of the velocities for interval 1-2!)

6. **Calculate.** The student exerted an upward force on the 566 g ball during interval 1-2. Assume that the size of this force was constant. Use Newton's 2^{nd} law to determine the size of this force.

Answers: (2) 55.6 cm, (5) 13.6 m/s^2, (6) 13.2 N

SPH3U: Testing Freefall Acceleration

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Last class we predicted that an object in freefall would accelerate downwards at a rate of 9.8 m/s^2. Our measured result from the velocity graph was different from this. We need to explore why.

A: Testing Hypotheses – Science!

When people see something strange happening, they invent *hypotheses*: different explanations for why something happens a certain way. A good hypothesis is specific and can be used to create a *prediction*: a description of what will happen in a situation according to a particular hypothesis. A prediction is only useful if it can be tested using an experiment.

1. **Hypothesize.** Create two different hypotheses that provide possible explanations why the measured acceleration result was different from the predicted value of 9.8 m/s^2. Try to be specific.

   (1)

   (2)

To test a hypothesis, you need to design a *testing* experiment. A good testing experiment will produce evidence that either supports or refutes the predictions made using different hypotheses. A poor experiment yields results that are ambiguous and don’t rule out any hypotheses.

2. **Design.** Create a testing experiment that will help support or refute one of your hypotheses above. Your experiment should involve materials and techniques that you are possible in our classroom. Describe your experiment.

** call your teacher over to provide feedback for your testing experiment **

3. **Predict.** If the hypothesis is correct, describe the outcome of the experiment.

4. **Test.** Record your observations from the experiment.

5. **Evaluate.** Decide whether the experimental result supports or refutes your hypothesis.

6. **Record.** Use at most 15 words to report your results on a whiteboard. **Briefly** state the hypothesis you tested and whether it was supported or refuted. Since there are always uncertainties in experiments, we want to look for a consensus in the class.

Summary of Freefall Model

The Air Resistance Assumption: In grades 11 and 12, the size of the force of air resistance (F_{air}) is almost always much smaller than the other forces involved. As a result, we will assume that the size of air resistance is zero. We will only include air resistance in a model if the situation does not make sense without it (like a person with a parachute).

B: The Freefall Problem

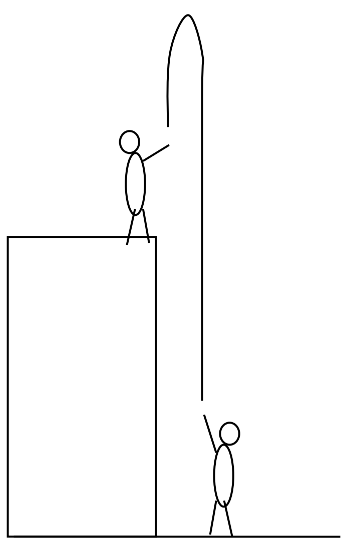
Timothy, a student no longer at our school, has climbed up on to the roof of our school. Emily is standing below and tosses a ball straight upwards to Timothy. The ball travels up past him, comes back down and he reaches out and catches it. Tim catches the ball 6.0 m above Emily's hands. The ball was travelling at 12.0 m/s upwards, the moment it left Emily's hand. We would like to know how much time this trip takes.

1. **Represent.** Complete part A below. Draw a coordinate system that shows the *y*-origin for position measurements and where upwards is positive. Only label the events that define the start and end moments of the problem.

2. **Represent.** Complete part B below. Make sure the two graphs line-up vertically. Draw a single dotted vertical line through the graphs indicating the moment when the ball is at its highest.

A: Pictorial Representation

Sketch, coordinate system, label givens & unknowns, conversions, describe events

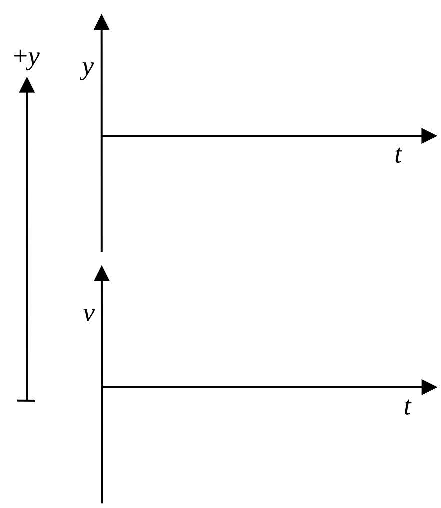


Event ①:

Event ②:

B: Physics Representation

Motion diagram, motion graphs, events



3. **Reason.** We would like to find the displacement of the ball while in freefall. Some students argue that we can't easily tell what the displacement is since we don't know how high the ball goes. Explain why it is possible and illustrate this displacement with an arrow on the sketch.

The total length of the path traveled by an object is the *distance*. The change in position, from one event to another is the *displacement*. Distance is a scalar quantity and displacement is a vector quantity. The magnitude of the displacement is the same as the distance only when then direction (the sign of the velocity) does not change.

4. **Reason.** The BIG 5 equations are valid for an entire interval of constant acceleration. Is the acceleration of the ball constant between the two events you chose? Explain.

5. **Reason.** Isaac says, "I want to use an interval of time that ends when the ball comes to a stop in Tim's hand. Then we know that $v_2 = 0$." Why is Isaac incorrect? Explain.

6. **Solve.** Choose a BIG five equation to solve for the time. (Hint: one single BIG 5 equation will solve this problem). Note that you will need the quadratic formula to do this! $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ For convenience you may leave out the units for the quadratic step.

D: Mathematical Representation

Describe steps, complete equations, algebraically isolate, substitutions with units, final statement

7. **Interpret.** Now we have an interesting result or *pair* of results! Why are there two solutions to this problem? How do we physically interpret this? Which one is the desired solution? Explain using a simple sketch.

8. **Interpret.** State your final answer to the problem.

Homework: Freefalling

1. Isaac is practicing his volleyball skills by volleying a ball straight up and down, over and over again. His teammate Marie notices that after one volley, the ball rises 3.6 m above Isaac's hands. What is the speed with which the ball left Isaac's hand? Hint: carefully choose your events and decide how the given information matches the events.

2. With a terrific crack and the bases loaded, Albert hits a baseball directly upwards. The ball returns back down 4.1 s after the hit and is easily caught by the catcher, thus ending the ninth inning and Albert's chances to win the World Series. How high did the ball go?

3. Emmy stands on a bridge and throws a rock at 7.5 m/s upwards. She throws an identical rock with the same speed downwards. In each case, she releases the rock 10.3 m above a river that passes under the bridge. Which rock makes a bigger splash? Hint: set this up as two problems, but draw your graphs on one set of axes.

Answers: (1) 8.40 m/s, (2) 20.6 m, (3) same

SPH3U: Interaction Forces

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

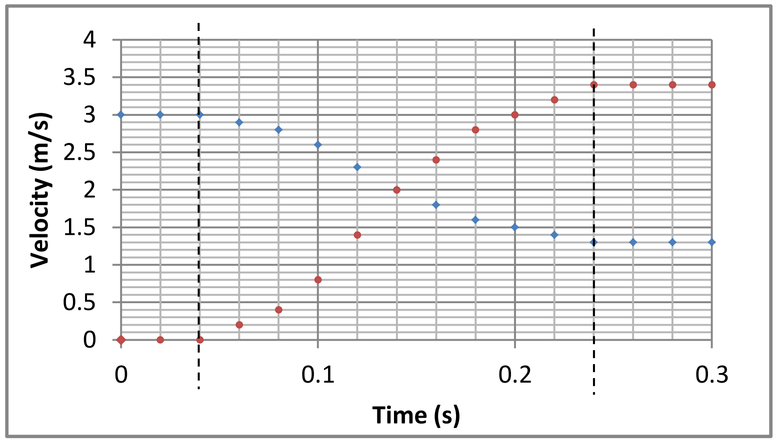
A: Truck vs. Car!

A fast moving truck collides with a Smart Car at rest. In this situation there are two possible forces: a force the truck exerts on the car, $F_{T\text{–}C}$, and a force the car exerts on the truck, $F_{C\text{–}T}$.

1. **Explain.** Why, according to common sense, might someone decide that $F_{T\text{-}C}$ is larger than $F_{C\text{-}T}$?

B: Analysis - Acceleration

We will model this collision with a large and small dynamics cart (500 g, 250 g). Using motion detectors, we can collect velocity data during their collision. This data is shown in the graph to the right. The positive direction is to the right.



1. **Explain.** How can we tell that the dotted vertical lines correctly represent the starting and ending moments of the collision?

2. **Interpret.** What is the duration of the collision?

3. **Calculate.** Use the velocity information to find the average acceleration (including direction) of each cart during the complete collision. Show all your work.

4. **Explain.** Which cart experienced the greater acceleration? Is this surprising? How does this agree with your visual impression of what happens?

5. **Reason.** Imagine the carts were vehicles in a collision. Based on the acceleration results, which one would you prefer to be in? Explain.

C: Analysis - Forces

It is clear from the data and your calculations that the small cart reacts more during the collision – its acceleration is the greatest. But this is not the end of the story. Acceleration is the *result* of force, and we have not yet found the forces responsible. In this collision, the forces the carts exert upon one another are much larger than the force of friction. Therefore it is reasonable to ignore friction and assume that there is only one important horizontal force acting on each cart.

1. **Represent.** Draw one single ID for the two carts and circle each cart showing that you are choosing <u>two</u> systems.

ID

2. **Represent.** Draw an FD for each cart. Label the forces F_{L-S}, meaning the force of the large cart on the small cart, and F_{S-L}, meaning the force of the small cart on the large cart.

3. **Calculate.** Use Newton's 2nd law to find the magnitude of the forces using your acceleration results. Watch the signs!

System = large cart	System = small cart
FD	FD
2nd Law	2nd Law

4. **Explain.** How does the magnitude of F_{L-S} compare with F_{S-L}? Is this result surprising? Why?

5. **Interpret.** The force results seem like a contradiction of our common sense. We must re-interpret what our common sense is actually telling us. When we observe a collision between a car and truck, are we observing forces or accelerations? Explain.

6. **Explain.** Another strange aspect of this result is that forces of equal size produce such different acceleration results. How is this possible?

D: Test this Idea

1. **Challenge.** We have explored just one situation and found that the sizes of the two interaction forces are the same. Maybe other situations are different? Maybe they are the same? Propose other situations involving the carts (you can change the masses, velocities, etc.) where you think the two interaction forces might be the same or might be different.

SPH3U: Newton's Third Law

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

The case we have just studied of colliding carts points to a very general law about forces. The idea that the interaction forces between two objects (the carts) are equal in size holds true for all physical objects. This idea is known as *Newton's 3rd Law*.

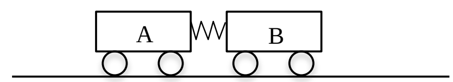
When objects interact, a pair of forces is always produced – they are two parts of one interaction. We call these two forces a *third law force pair*. The two forces that are members of the same third law pair share some important characteristics.

- the same magnitude
- opposite directions
- the same type (gravitational, normal, tension, etc.)
- start and stop acting at the same time
- act on different objects

We can use *3rd law notation* for forces to help show these relationships. $\vec{F}_{n\,c-t}$ means the normal force of the car acting on the truck. According to Newton's 3rd law, the partner to this force in a 3rd law pair is $\vec{F}_{n\,t-c}$, the normal force the truck exerts on the car.

A: Exploding Carts!

Your teacher has two equal-mass dynamics carts on a track. Cart A has a compressed spring attached. Your teacher will release the spring and we will focus on the interval of time when the spring is expanding and affecting the carts.



1. **Represent.** Draw a single ID for the two carts, with each as a separate system. Draw a FD for each cart using 3rd law notation. The spring force is an *elastic* force.

ID	FDs

2. **Predict.** How will the speeds of the two carts compare after the spring is released? Use both Newton's 2nd and 3rd laws to justify your prediction.

3. **Test.** (*as a class*) Describe your observations. Do they agree with your predictions?

4. **Predict.** (*individually)* A large mass is added to the cart with the spring. Draw the FDs for when the spring is released. In this situation, how do you think the two cart velocities compare? Explain.

FDs

5. **Test.** (as a class) Describe your observations. Do they agree with your predictions?

6. **Reason.** Marie says, "In this situation, the cart **without** a spring will not exert a force on the cart with the spring. It just sits there passively and gets pushed by the spring." Emmy says, "I think the cart without the spring does push on the other cart." Use your observations to explain who you agree with.

B: The Apple and the Earth

The story goes that our friend Sir Isaac Newton made a great discovery while he was sitting under an apple tree and an apple happened fall down on him.

1. **Represent.** Draw an ID and FD for the apple while it is at rest on the ground. Label each force using the 3rd law notation.

2. **Reason.** Albert says, "The two forces on the FD above must be third law pairs - they are equal in magnitude and opposite in direction." Do you agree or disagree? Explain.

ID	FD

3. **Represent.** Draw a single ID for the apple and the earth while *the apple is falling*. Circle each object as a separate system. Draw the FDs for each system. (Hint: use the 3rd law!)

4. **Reason.** Use the 1st law to predict the state of motion for each system.

ID	FD Apple	FD Earth

5. **Explain.** One of your predictions probably seems a bit strange. Describe why it seems strange.

6. **Calculate.** The apple has a mass of 0.2 kg. What is the magnitude of the force of gravity it experiences?

7. **Calculate.** Earth has a mass of 6.0×10^{24} kg. Use the 3rd law to determine the magnitude of the force of gravity of the apple acting on Earth. Then use the 2nd Law to calculate the acceleration of Earth.

8. **Reason.** Isaac says, "The earth clearly doesn't move! I don't believe that it experiences an equal size force as the apple." Do you agree or disagree? Explain.

SPH3U: Newton's 3rd Law Homework Name:

A: Physics on Ice

You have brought your little cousin out skating for the very first time. Both of you are standing on the ice wearing skates (no friction) and are facing one another. Your little cousin is a bit timid and needs to hold on to your scarf while you pull.

1. **Represent.** Draw and ID that includes you and your cousin. Draw a FD for you and a FD for your cousin.

2. **Calculate.** Your cousin holds on while you gently pull the scarf with a 6 N force to start her moving. Her little mass is 17 kg. Determine her speed after pulling for 2.0 s.

ID	FD Cousin	FD You

3. **Reason.** Albert says, "I understand why the cousin speeds up – you are pulling on the scarf and she holds on. But I don't predict you will move. Your cousin is only holding on, not pulling. And, in any case, she is much smaller so she couldn't pull you anyways." Do you agree or disagree? Explain.

4. **Represent and Calculate.** Use your actual mass to determine your speed after the same 2.0 seconds of pulling.

B: A Big Push

Your friend is sitting on a skateboard. You stay in place on the road and give her a big push forwards to start her moving. The road is a bit bumpy, so the skateboard experiences some friction. You push on her with a 23 N force. The mass of your friend is 49 kg and the skateboard is 3.1 kg. While you push, your friend accelerates at 0.4 m/s^2. Find the size of **all** the horizontal forces in this situation. Use a solution sheet to show your work, include a **single** interaction diagram showing two systems (you and your friend), and draw a force diagram for each system.

Answers: (A#2) 0.706 m/s, (B) on you (23 N, 23 N), on your friend (23 N, 2.16 N)

SPH3U: Friction Homework! Name:

A: Friction Lesson Day 1

1. **Represent.** You are reorganizing your room and attempting to move your bed to a new location. You push on the bed, away from the wall, with a 127 N force, but it does not move. Draw an ID and FD for this situation. Write an expression for Newton's 2nd Law in the *x*- and *y*-directions. Use your expressions to find the size of the force of friction.

ID	FD	$F_{net\ x}$ and $F_{net\ y}$

2. You have found a summer job working for Amazon pushing boxes in one of their enormous warehouses. You pushed very hard on one box that turned out to be quite light, so you ended up pushing it much faster than you expected! After it left your hands, it ended up sliding far across the floor before stopping. There are three important events: (1) the box begins to move, (2) you release the box, and (3) the box stops moving.
   (a) **Represent.** Draw an ID and FD for the system of the box during the two intervals.

ID (1-2)	FD (1-2)	ID (2-3)	FD (2-3)

   (b) **Describe.** Explain how you decided to draw the size of the force of friction vectors in your two force diagrams.

B: Friction Lesson Day 2

1. After learning more about friction, you are ready to try moving your bed again. This time, you exert a strong, steady force of 247 N and the bed starts moving. The coefficient of kinetic friction between the bed and floor is 0.53. The bed has a mass of 41 kg. Our goal is to find the acceleration of the bed.
   (a) **Represent.** Draw a force diagram for the bed. (How is this different from Q A#1?)
   (b) **Represent.** We want to build up good habits for showing our understanding when solving friction problems. In each problem, it is always a good idea to carefully write out the *x*- and *y*-components of Newton's 2nd Law. Do this here.

FD

   (c) **Reason.** Friction problems often involve analyzing vertical forces (since the normal force is important) and horizontal forces (since the friction force is important). For each symbol in the two expressions above, we need to decide: do we know this quantity, or can we find it using some other idea? Complete the chart below.

x-direction		*y*-direction	
Quantity	Decision	Quantity	Decision
F_a		F_n	
F_f	use $F_f = \mu_k F_n$, but we don't know F_n!	F_g	
m	given in the problem	m	
a_x		a_y	

   (d) **Reason.** Now we need to make a decision: should we start our solution work with the *x*-or the *y*-component of the 2nd law? In which direction do we have the fewest missing quantities?

   (e) **Complete.** On a separate solution page, complete this problem and the LeBron James question.

Answers: Bed question: a = 0.830 m/s^2, LeBron question: μ = 4.03

SPH3U: Friction

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Athletes are paid millions of dollars every year to endorse fancy shoes. Perhaps they do have some expertise in the matter – maybe the shoes do have an effect on their performance. What makes for a superior shoe? Perhaps it has something to do with friction!

A: Shoe Friction

1. **Reason.** Do you think an athlete wants their shoes to have lots of friction or little? Explain.

2. **Reason.** There are many types of shoes (or footwear) in the world. Which ones do you think have lots of friction? Which have little?

B: The Types of Friction

At the front of the class your teacher has a fairly heavy object and force sensor. Watch as your teacher will gradually exert a larger force on the object using the spring attached to a sensor until the object starts to move. No data will be collected yet.

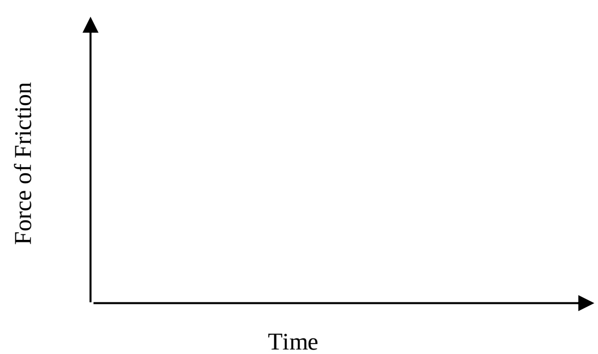
1. **Represent.** For each situation below draw a force diagram for the object. Compare the size of the horizontal forces that may be involved in a particular situation.

(A) Your teacher is not pulling on the object	(B) Your teacher is gently pulling, but it is not yet moving	(C) Your teacher is pulling hard, but it is not yet moving	(D) Your teacher is pulling and it is now moving at a constant velocity
FD	FD	FD	FD
Compare:	Compare:	Compare:	Compare:

2. **Reason.** In which situations above is the force of friction present? What evidence is there? Explain.

3. **Observe.** (*as a class*) Your teacher will now pull on the object while the computer records the data. Sketch a simplified version of the force data on the graph to the right and label the event when the object begins to slide.

4. **Describe**. What happens to the size of the friction force when the object begins to move?



Friction is a contact force that occurs when two objects that are pressed together try to slide against one another. If the surfaces are sliding relative to one another we call the force *kinetic friction* (F_{fk}). If the two surfaces are not slipping we call the force *static friction* (F_{fs}).

5. **Describe.** Label the force diagrams above with the appropriate type of friction.

6. **Reason.** What happens to the size of the force of static friction if we pulled a bit harder and the object still did not move? Explain.

The size of the force of static friction can take a range of values depending on what is happening in the particular situation. $0 < F_{fs} \leq F_{fs\ max}$. There is a maximum possible value for the force of static friction which occurs just before the objects begin to slip. This maximum value is usually greater than the force of kinetic friction.

C: Shoe Physics!

We want to compare the friction of one shoes with another, but there is an important problem:

How does the size of the force of kinetic friction depend on how hard the shoe is pressing into the ground?

1. **Reason.** Which force represents how hard the two objects are pressing against one another? Using the same shoe, how can we change the size of the friction force? Explain.

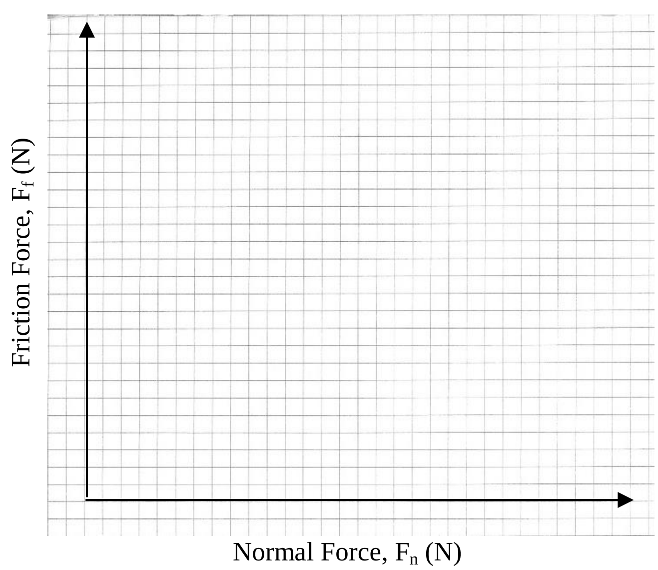
2. **Design an Experiment**. Use a spring scale, your group's shoe and some masses. Describe the procedure of an experiment that will adress the question above. Draw a force diagram for your experiment.

FD

*** check your experiment with your teacher before continuing ***

3. **Observe and Represent.** Collect data according to your procedure. Plot the data <u>comparing the forces</u> on the graph.

Mass (kg)	F_n (N)	F_f (N)



4. **Find a Pattern.** Describe how the size of the force of friction depends on the size of the normal force.

5. **Analyze.** Construct a line of best-fit for your data. Determine the slope of the line. Show your work below.

6. **Report**. Check with your teacher. Record the slope result for your shoe on a white board. Once the class is ready we will share these results. Move on for now.

7. **Interpret.** The value you found for the slope is called the *coefficient of kinetic friction* (μ_k). What characteristics of your experiment do you think affect this value? What is this value a measure of? What would a smaller value for μ_k signify?

8. **Analyze.** Construct an equation for the line of best fit for your graph. Use the symbols F_n, μ_k and F_{fk}.

9. **Calculate.** If a 230 lb (1 kg = 2.2 lbs) basketball player wore your shoe (which may defy other laws of physics!) what would the force of kinetic friction be? Show your work.

E: How the Surfaces Affect Kinetic Friction

1. **Speculate.** Why do you think there is friction between two surfaces?

2. **Predict.** What kinds of surfaces will produce little friction and what kinds will produce great friction?

In the next experiment you will investigate what combination of surfaces will produce the most friction. Make sure that you use a fairly clean surface, otherwise you will be measuring the forces from grinding dirt. Drag the shoe with a bit of extra mass over four surfaces (table, glass, floor, one more of your choice).

3. **Observe.** What is the total mass of your shoe?

4. **Predict.** Choose your fourth surface. Which surfaces do you think will yield high, medium or low friction?

Lower Surface	**Prediction**	**Force of Friction (F_f)**	**Normal Force (F_n)**	**Coefficient (μ_k)**
Table				
Floor				
Glass				

5. **Observe.** Measure the force of friction in each case. Record your results in the chart above.

The *coefficient of kinetic friction* (μ_k) depends on the physical properties (roughness, chemical composition) of the pair of surfaces and is related to the force of friction by the expression: $F_{fk} = \mu_k F_n$. Since the force of kinetic friction is usually different from the maximum force of static friction, there is a separate *coefficient of static friction* (μ_s). We can find the maximum force of static friction using the expression: $F_{fs\ max} = \mu_s F_n$.

6. **Calculate.** Find the coefficient of kinetic friction for the combination of surfaces in your experiment and add these to the table.

7. **Describe.** Were there any surprising results? What does this imply about the floors of professional basketball courts?

8. **Calculate.** (First, try out the friction homework – part B on the homework page. Then, tackle this problem.) LeBron James (113 kg) comes charging down the basketball court, running at 6.3 m/s. He tries to stop moving and ends up sliding along the floor for only 0.5 m. We want to model this situation and find the coefficient of kinetic friction for his shoes and the basketball court floor. Complete this on a solution sheet.

   Ideas to check:
   (1) How does the direction of LeBron's velocity compare with his acceleration?
   (2) While he is sliding to a stop, what objects is he interacting with? Only draw force vectors for those external interactions!
   (3) Work backwards from our goal. We want to find the coefficient. Which equation has μ_k? When do we need to know to find μ_k? So we need to find the … and keep going!

SPH3U: Tracking Energy

Recorder: __________________
Manager: __________________
Speaker: __________________
0 1 2 3 4 5

Energy is a mysterious quantity. We need to develop our detective skills so we can decide where energy is hidden and how much is there. Once we do that, and learn to track energy as it moves around, energy becomes a very powerful tool for understanding our universe.

A: Detecting Energy

For convenience, we will call one unit of energy a *block* of energy. A great challenge for us is that no one can see a block of energy. It's a bit like looking for a black hole in space: you can't see it (it's black!), but you can still tell that it's there (a great force of attraction and all that destruction!). We need to figure out how to detect where blocks of energy are hidden or *stored*. The different ways in which energy can be stored are called *storage mechanisms*. We give blocks of energy a label depending on the way they are stored, for example, *kinetic* energy. But remember, the energy is not any different: it's always the same old block of energy, just stored in a different way.

We need to find a way to measure how much energy is stored in each mechanism. These measurements involve a comparison of the characteristics of an object or system (like speed, position, temperature) at two moments in time. Together, the characteristics that can be measured make up the *state* of the system.

1. **Reason.** In elementary school you learned that energy can be stored in the motion of an object. We label blocks of energy stored this way *kinetic* energy. Imagine that we compare the state of an object at two moments in time. What might be different about the state of that object at those two moments that provides the clue that there is kinetic energy? What could we measure to carefully track this?

For the next set of questions, you will make use of a pullback car. We define four events to help us clarify what is happening:

(1) The hand begins to pull backward on the car.
(2) The hand stops pulling backward and is about to release the car.
(3) The car reaches its top speed.
(4) The car finally stops.

2. **Observe.** Pull back the car and let go, following the events above. Describe what is happening during interval 2-3.

3. **Explain.** The car reaches its top speed at moment 3. Between moments 2 and 3 there is a change in the amount of energy stored in the car's motion. Describe what has happened to the number of blocks of kinetic energy stored in the car.

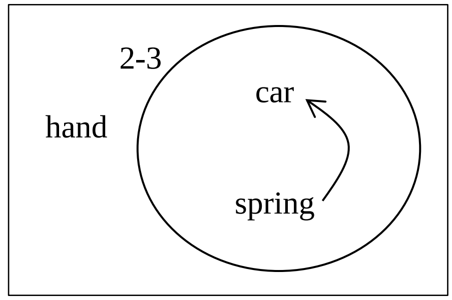
When we track energy and notice a change in the amount of energy stored, we must ask an important question: where did these blocks of energy come from, or where did they go? When we do, we discover that the blocks *transfer* or *flow* from one storage mechanism or object to another. Tracking these flows or transfers is an important part of finding hidden energy.

4. **Reason.** Between moments 2 and 3 we noticed an increase in kinetic energy. Where did these blocks of energy come from? If we could look inside the car, what could we observe and measure to help track the amount of energy stored at moment 2?

An *energy flow diagram* shows the flow of energy between different objects. We write the names of the objects that are interacting **and** participate in a flow of energy. We draw a circle around the objects that we choose as our *system*. Then we draw arrows that show the flow of energy between the objects during a specific interval in time. Objects outside the system are in the *environment*.

5. **Interpret.** In the situation we are exploring, there are three possible objects that might participate in a flow of energy: the hand, the spring (inside the car) and the car (the rest of the cart). According to the energy flow diagram shown to the right:
   (a) Which objects are system objects? Which are environment objects?

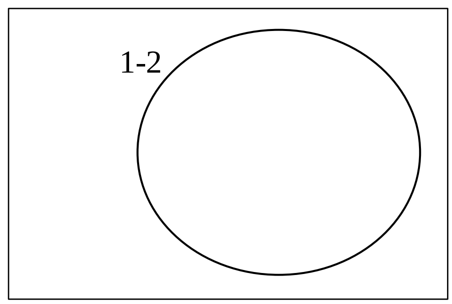
   (b) Which object is gaining energy? Which is losing energy?



6. **Reason.** At moment 3 the car reached its top speed. At moment 4 it came to rest on the table. Once again, there is a change in the number of blocks of kinetic energy. What happened to these blocks of energy? They might have just disappeared, but we are hoping that they are just hidden in a new and sneaky way. If we could look inside the car, what skillful measurement could we make to help find where the blocks of energy are now stored?

Energy can be stored in the random vibrations of an object's atoms, which we perceive at *thermal* energy. This often happens when objects or surfaces are rubbing against one another and interact through friction.

7. **Reason and Represent.** Time to complete our detective work. At moment 2 we know that energy is stored in the spring of the car. Where did these blocks of energy come from? Explain. Draw an energy flow diagram for interval 1-2. **System = car, spring**



8. **Interpret.** According to your energy flow diagram for interval 1-2, is energy flowing in to our out from the system?

9. **Explain.** We are constructing a model for how energy flows. What assumptions have we made about the energy flow in our model?

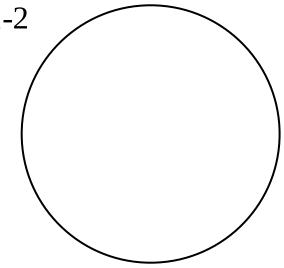
The energy flow diagram is based on the idea that a block of energy cannot be destroyed (it can't just disappear) and a block of energy can't be created (it can't just pop into existence). This is a very powerful idea called the *conservation of energy*. As a result, all the blocks of energy that leave an object or system must end up somewhere else – we should always be able to track them!

C: Going Up the Hill

Your teacher has a cart set up at the bottom end of an inclined track. It has a built-in spring that is initially compressed. There are three important events: (1) the spring is triggered and begins to expand, (2) the cart is moving and the spring is now fully expanded, and (3) the cart reaches its highest point on the track. **System = cart, spring**

1. **Represent and Explain.** Draw an energy flow diagram between moment 1 and 2 only. Describe any energy transfers or flows.

1-2



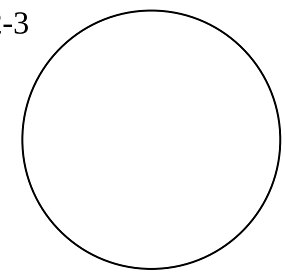
2. **Reason.** Between moments 2 and 3, how is the amount kinetic energy changing? Where do you think the blocks of energy are going?

> When the energy of an object changes due to a gravitational interaction with Earth, there is a change in the amount of energy that is stored in Earth's *gravitational field*. We label any units of energy stored in Earth's gravitational field *gravitational* energy. When this happens, we write "Earth" in our system as a short form for "Earth's gravitational field"

3. **Reason.** Isaac says, "I think energy is flowing from the cart to the track between moments 2 and 3." Do you agree or disagree with Isaac? What test could you make to support or refute Isaac's idea?

4. **Represent and Explain.** Draw an energy flow diagram between moments 2 and 3. **System = cart, spring, Earth.** Describe any energy transfers or flows.

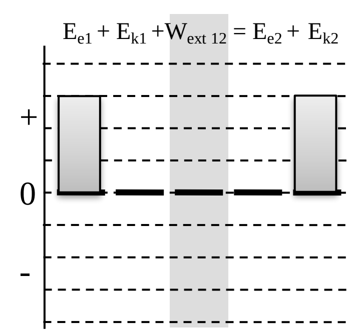
2-3



> An *energy bar chart* uses a bar graph to show the amount of energy (the number of blocks) stored among the **system objects** at two different moments in time. Unless you know (or can guess) exact values, the height of the bars is not important as long as the bars clearly show the right ideas. The middle bar in the chart, W_{ext}, represents the energy flow into or out of the system during the interval of time. Each energy symbol uses a subscript to indicate how the energy is stored.

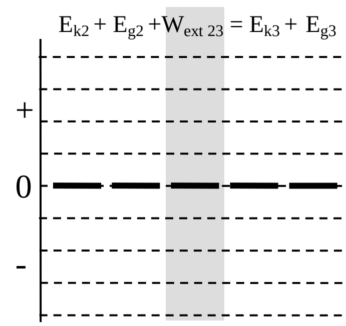
Label	**How it's stored**	**Measureable Characteristic**
Kinetic (k)	In the motion of the object	speed
Thermal (th)	In the motion of microscopic particles in object	temperature
Gravitational (g)	In the interaction between Earth and the object (in the *gravitational field*)	vertical position
Elastic (e)	In the stretch of the object (in its change of shape)	length
Chemical (c)	In the chemical bonds between particles	number of molecules

5. **Interpret.** An energy bar chart is shown for the cart between events 1 and 2. Explain what the bars are telling us about energy during this interval. What are we assuming about the amount of gravitational energy at moments 1 and 2?



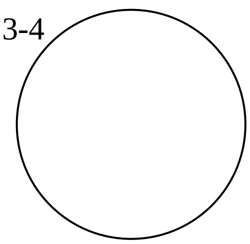
The energy change thinking process. To construct a bar chart, you need to decide how the system energies are changing. Start by asking yourself: "what characteristics of the system are changing between the two moments in time." Look at the chart above for examples of measured characteristics. Use this to decide which bars in your chart need to change.

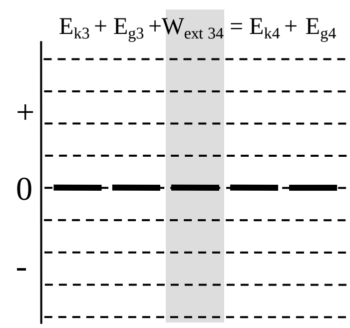
6. **Explain and Represent.** Which characteristics of the system change between events 2 and 3? As a result, which energies are increasing or decreasing? Draw an energy bar chart for the system between moments 2 and 3.



7. **Predict**. Now we will consider what happens when the cart returns back to the bottom of the incline. This will be event 4. Draw an energy flow diagram and energy bar chart between moments 3 and 4. According to your diagrams, explain how the speed of the cart at moment 4 will compare with its speed at moment 2.

3-4





8. **Reason.** The prediction you have made for the speed at moment 4 is based on one very important assumption.
   (a) What are you assuming in this model?

   (b) If your assumption is reliable, but not quite perfect (like most assumptions!) what should you notice when you test your prediction?

   (c) If the assumption is a poor one, what would a test of your prediction likely show?

9. **Test and Evaluate.** Test your prediction using the track and motion sensor set up in your classroom. Make a rough sketch of the velocity graph from the computer. Label the important events on your graph and use them to evaluate the quality of your assumption.

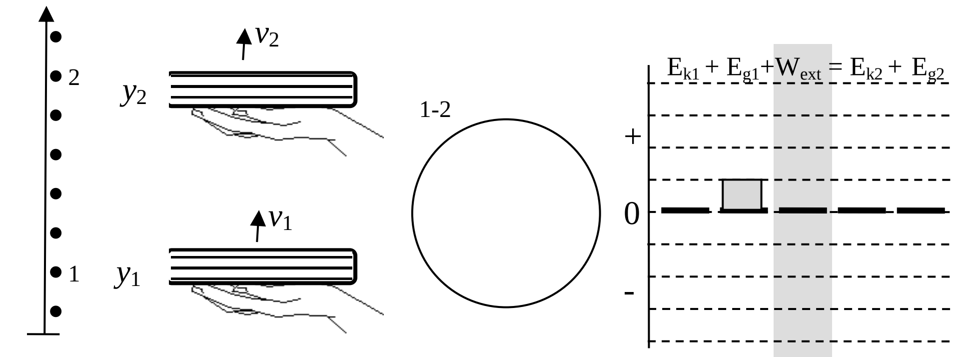
SPH3U: Tracking Energy Homework Name:

Energy Thinking Process: To understand energy flows, we need to decide what is happening to a system's energy. The thinking process involves two important decisions:

(1) **Decide which measureable characteristics of the system are changing**. You can ask questions like: "is the object's *speed* changing?" or "is its *vertical position* changing?" This helps us understand how energy is being stored within the system at different moments in time.

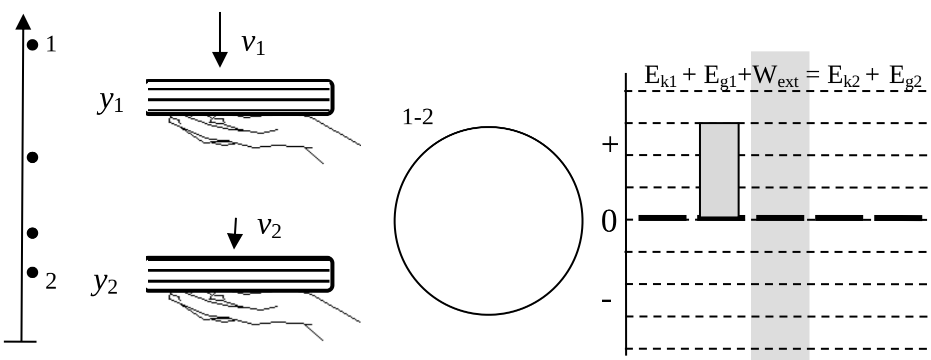
(2) **Decide whether the system total of energy is changing**. You can ask yourself questions like: "are there any objects in the environment that are adding energy to or removing energy from the system?" This helps us understand if there is any energy flow in or out of the system.

1. **Represent and Explain.** Emmy is moving a book with her hand. Four different situations are shown below. The motion diagram shows the two events we will focus on. Complete an energy flow diagram and bar chart. **System = book, Earth**. Explain: is energy entering or leaving the system? What are the changes of energy?



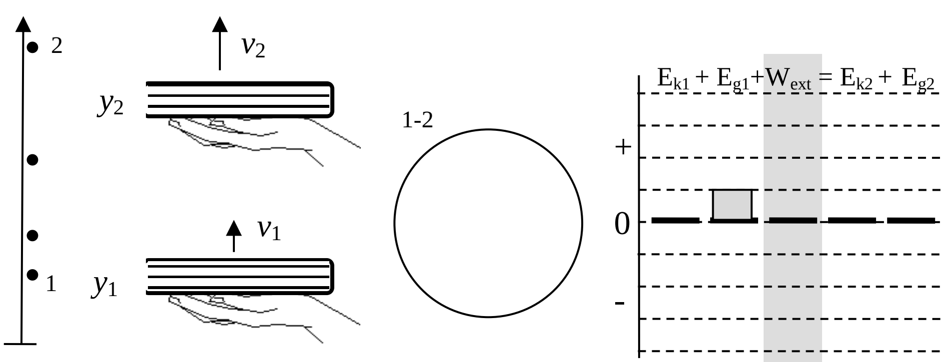
Energy entering or leaving system?
Energy is entering the system

Describe flows: Energy flows from the hand to the book and then from the book to Earth's gravitational field. E_k stays the same (constant velocity) and E_g increases (moving upwards)



Energy entering or leaving system?

Describe flows:



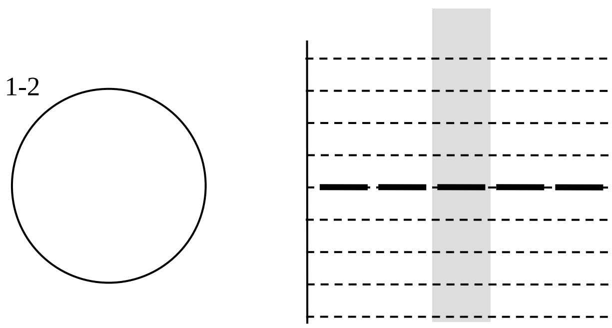
Energy entering or leaving system?

Describe flows:

SPH3U: Energy Challenge Homework Name:

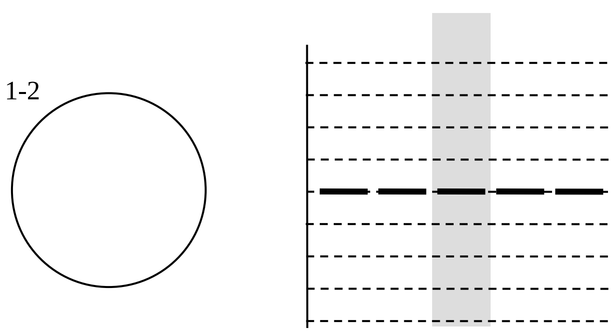
This is the homework for the last lesson in the energy unit.

1. **Represent.** A car is speeding travels along York Mills Road. At the moment that it begins to travel up a hill, the driver spots an accident ahead and slams on the brakes. The car skids to a stop as it travels up the hill. Complete an energy flow diagram, work-energy bar chart and equation for this situation.



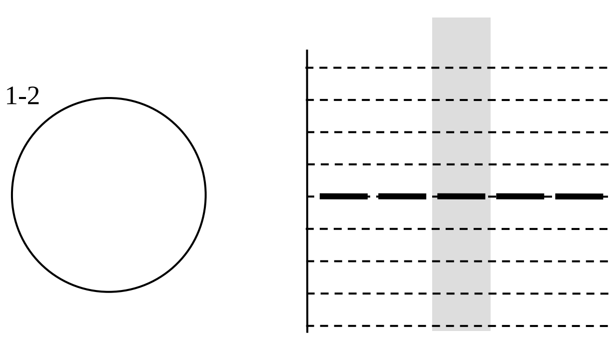
Work-energy equation:

2. **Represent.** A ski resort uses a motor and a rope to pull beginning skiers up a small hill. A skier starts at rest at the bottom of the hill, grabs the rope, and is pulled at a constant speed to the top of the hill. Complete an energy flow diagram, work-energy bar chart and equation for this situation.



Work-energy equation:

3. **Represent.** The engine of a car transfers the energy stored in gasoline, into thermal energy of the combusted byproducts, into kinetic energy of the vehicle. In a typical car, 20% of the energy stored in the gasoline becomes kinetic energy. At moment 1, the car has 1 L of gasoline in its tank. At moment 2, that amount of gasoline has been burned.



Work-energy equation:

4. **Solve.** Complete question #2 above. A 57 kg skier is pulled up the hill at a speed of 1.1 m/s. The top of the hill is 13.7 m above the bottom. A trip up the hill takes 23 seconds. What is the power output of the motor while pulling this skier?

  Answer: #4. 334 W

SPH3U: Doing Work!

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

How do we track the transfer energy into or out of a system? Let's find out!

A: The Energetic Cart

You need a dynamics cart for this part of the investigation. The force of friction is very small compared with other forces.

1. **Describe and Represent.** We want some energy to flow from your hand to the cart. Describe how you can do this. Draw a motion diagram, a force diagram, and an energy flow diagram during this process (while it gains kinetic energy). **System = cart**

$+x$

FD

2. **Describe and Represent.** The cart is initially moving quickly and we want energy to flow from the cart to your hand. Describe how you can do this. Draw an MD, FD, and an energy flow diagram during this process. **System = cart**

$+x$

FD

3. **Demonstrate**. Use the cart and show these two situations to your teacher. Move on while you wait.

Energy can be transferred into or out of a system by an external force. When this happens we say that the force does *mechanical work* (or often just *work*) on the system. When energy flows out of the system due to the force, the system loses energy and we say that the force does *negative work* on the system. When energy flows in to the system, the system gains energy and we say the force does *positive work* on the system. Energy is a scalar quantity and positive or negative work does not indicate any kind of direction, it only indicates a gain or loss for that object.

4. **Explain.** In which case above was the work positive or negative. Explain.

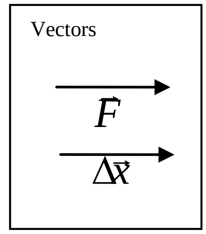
5. **Reason.** Think about the first situation. What do you think would happen to the amount of energy that flows into the system if your hand exerted the same force for twice the distance? Explain.

6. **Reason.** Think about the second situation above. If the force you exerted was twice as large, what would happen to the distance? Explain.

The work done by a force on a system (W) depends on three quantities: the size of the force (F), the displacement of the system (Δd) and the angle between the force vector and the displacement vector (θ). These are related by the expression, $W = |F||\Delta d|\cos\theta$. The units of work may be expressed as N·m, but these are actually equivalent to the unit joules (J) for energy.

B: Working the Angles

1. **Reason and Calculate.** A cart with a mass of 0.70 kg is initially at rest. Then it is pushed horizontally by a hand with a force of 10 N. Friction is negligible.
   (a) Vector arrows showing the direction of the force from the hand and the displacement of the cart are drawn for you. Draw an energy flow diagram for the system of the cart.



   (b) What is the angle between the two vectors? (The angle represents the *difference* in direction of the two vectors)

   (c) After it moves a distance of 0.40 m, how much work (in joules) has been done by the force?

   (d) Interpret the sign of the value for the work that you calculated. How much kinetic energy do you think the cart has now?

2. **Reason and Calculate.** The same cart is rolling along a table and is released. It collides with a block that exerts a 12 N stopping force on the cart. It rolls 0.35 m while stopping.
   (a) Draw vector arrows for the block's force and the displacement of the cart. Draw an energy flow diagram for the system of the cart.

Vectors

   (b) What is the angle between the two vectors? What is the work done by the block's force while bringing the cart to rest?

   (c) Interpret the sign of the value for the work that you calculated. How much kinetic energy do you think the cart originally had?

3. **Reason and Calculate.** Now you push on the cart for 0.50 m while the cart pushes against the block. The block's force is still 12 N and you push horizontally with a force of 15 N.
   (a) Draw energy flow and force diagrams for the system of the cart.

FD

   (b) Calculate the work done by each force acting on the system.

   (c) What is the total work done on the system? How much kinetic energy did the system gain during this process?

When our system is a **point particle**, we use the *net work* is the sum of all the work done on the particle. If the net work is positive, the particle *gains* kinetic energy. If the net work is negative, the particle *loses* kinetic energy. This idea is called the *net work - kinetic energy theorem* and is represented by the expression: $W_{net} = E_{k2} - E_{k1} = \Delta E_k$. Note that this is the same as finding the work done on the particle by the net force vector: $W_{net} = |F_{net}||\Delta d| \cos\theta$.

SPH3U: Doing Work Homework Name:

A: The Toy Car

You are playing with a little kid, pushing a toy car across the floor and making “vroom, vroom” sounds. During a “car crash” you push the car into a soft stuffed animal.

1. **Represent**. Draw an energy flow diagram and a force diagram for the system of the car. Use F_c to label the contact force of the stuffed animal.

2. **Reason.** Which forces do you think cause energy to flow in or out of the system? Explain.

FD

3. **Reason.** Use the new expression for work ($W = |F||\Delta d|\cos\theta$) to help complete the chart for each force acting on the car.

4. **Reason.** During the car crash is energy flowing in or out of the system? Explain how you know.

Force	θ	Sign of work? (+, - or 0)	Flow of energy? (in, out or none)
F_a			
F_c			
F_n			
F_g			

5. **Reason.** Do forces acting perpendicular to the displacement of an object transfer energy in or out of a system? Explain.

6. **Reason.** Did the sign of the work depend on our choice of a sign convention? (Did we make such a choice?) Explain.

7. You continue to push on the car (and so does the stuffed animal), but it is now speeding up.
   (a) **Reason.** Is this situation accurately described by the FD and energy flow diagram above? Would you need to make any changes? Explain.

   (b) **Reason.** Is the car gaining or losing kinetic energy? Use the *kinetic energy-net work theorem* to determine the sign of the net work.

   (c) **Reason.** How does the amount of energy transferred by each force compare in this situation?

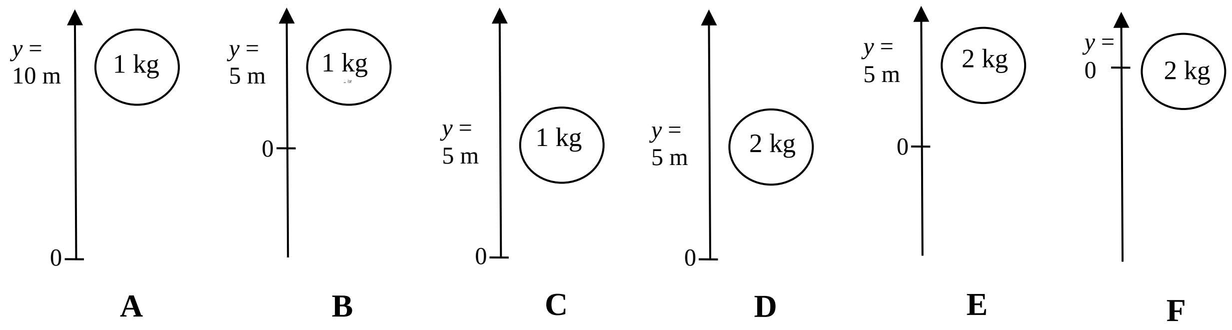
8. **Calculate.** The size of your push is 1.1 N. The contact force from the stuffed animal is 1.4 N. The car initially had 0.05 J of kinetic energy. How far does it travel before stopping?

Answer: #8 0.167 m

SPH3U: Measuring Energy Homework   Name:

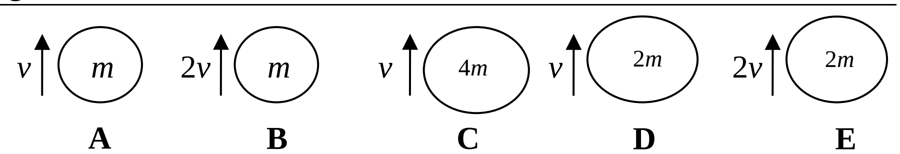
A: Comparing Gravitational Energies Using $E_g = mgy$

1. **Reason.** Six objects and their vertical positions relative to an origin are shown. Rank the gravitational energies of each object relative to its vertical origin. Explain your ranking.

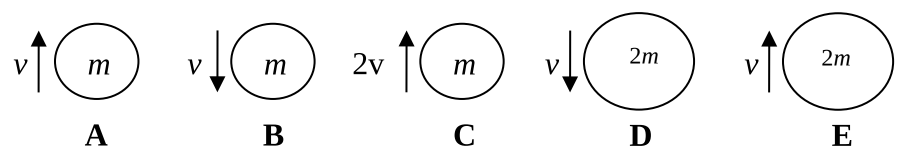


B: Comparing Kinetic Energies Using $E_k = ½mv^2$

1. **Reason.** The velocity and mass of five objects is shown to the right. Suppose v = 1 m/s and m = 1 kg. Rank the amount of kinetic energy each object has. Explain your ranking.



2. **Reason.** The velocity and mass of five objects is shown to the right. Suppose v = 1 m/s and m = 1 kg. Up is positive and down is negative. Rank the amount of kinetic energy each object has. Explain your ranking.



C: Calculating Energies

1. **Reason**. A friend shows you the results of his calculations. (a) Explain what errors he made and (b) correct his work.

m = 250 g
v_1 = 5.0 km/h
y_1 = 3.4 m

$E_{g1} = mgy_1$ = (250 g)(9.8 N/kg)(3.4 m) = 8330 J

$E_{k1} = ½mv_1^2$ = (0.5)(250 g)(5.0 km/h)^2 = 3125 J

2. **Reason.** Two identical test cars are driving down a test track and hit their brakes at the same position. One car is travelling at twice the speed as the other. (a) Compare the kinetic energies of the two cars. (b) Use the idea of work to explain how much farther the faster car travels while braking.

Answer: C#1 E_{g1} = 8.33J and E_{k1} 0.241 J

SPH3U: Measuring Energy

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

The idea of work provides us with a handy way to measure the amount of energy transferred during some process involving forces. Now we need to use work to find out how much energy transfers into kinetic or gravitational energy.

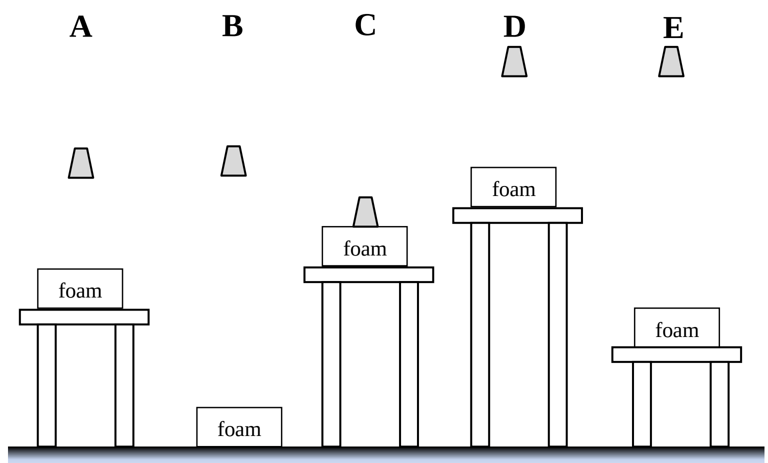
A: Making Dents

Imagine you lift up a heavy weight and place a foam block underneath. You let go of the weight and it falls on top of the block. A dent is left in the piece of foam.

1. **Explain.** How does energy flow while you lift the heavy weight?

2. **Reason.** What could you change about this situation to change the size of the dent in the same foam block?

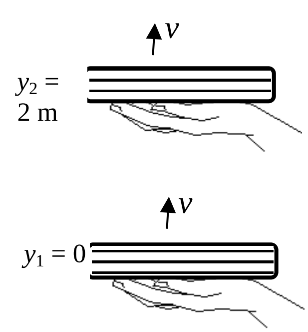
3. **Reason.** A foam block is placed on different tables with different heights above the floor. The weight is released from different positions above the floor. Rank the size of the dent created in each foam block. Explain your ranking.



When we lift an object, energy is transferred due to the gravitational interaction between the object and Earth. We say that the energy is stored in the earth's *gravitational field*. The energy is not stored in the object itself – we notice no difference in the properties of the object. When we include the earth in our system, we always include its gravitational field.

B: Work and Gravitational Energy

Let's go back to an earlier example. Emmy holds a book of mass *m* in her hand and raises the book vertically at **constant** speed.



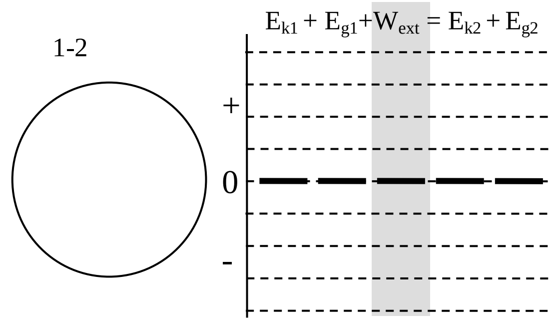
1. **Describe.** During the process of lifting the book, describe the transfers of energy that occur.

2. **Reason.** Suppose we changed y_1 and y_2 by moving each of them one metre upwards. Would this change affect the amount of energy that flows or is transferred in this situation? Explain.

Only the change in an object's vertical position affects the amount of energy flowing in or out of Earth's gravitational field, since we assume the gravitational force is constant. This gives us a freedom to choose a *zero point* for gravitational energy: at a chosen vertical position, we **set** the amount of energy stored in the gravitational field equal to zero.

3. **Represent and Describe.** Complete the energy flow diagram and bar chart for the book-earth system. The diagram on the previous page shows your *zero point* for the gravitational energy. Get in the habit of labelling your vertical positions "y_1", "y_2", like in that diagram.

4. **Explain and Calculate.** The amount of energy stored as gravitational energy is equal to the amount of work done by the force of the hand on the book. Explain how to find the **size** of this upwards force. Carefully show how to create an expression for the work using the symbols *m*, *g* and y_1 and y_2.



The *gravitational energy* (E_g) of an object of mass, *m*, located at a vertical position, *y*, away from the vertical origin is given by the expression, $E_g = mgy$. The *zero point* is a vertical position where y = 0 and the gravitational energy equals zero. So we always say that an object has a certain amount of E_g *relative* to the vertical origin of a coordinate system. A very careful way of describing this is to say that E_g is the amount of energy we would need to add to the system to move the object from the zero point to the vertical position *y*.

Note that the units for work and gravitational energy are N·m. By definition, 1 N·m = 1 J, or one *joule* of energy. In fundamental units, 1 J = 1 kg·m^2/s^2. Remember: in order to get an answer in *joules*, you must use units of kg, m, and s in your calculations! Always use a positive value for *g* in your calculations and choose upwards as positive – this is our *energy-position* sign convention.

C: Work and Kinetic Energy

Another example that we looked at earlier was our cart which was at rest and then speed up as we pushed on it with our hand.

1. **Explain.** We are going to create an expression to help us find the kinetic energy of our cart after we push on it. For each step you see in this process, explain the ideas used to get from one step to the next.

Steps	Description
1) $E_{k2} = E_{k1} + W_{net}$	*The final kinetic energy is equal to the initial kinetic energy plus any energy added to the system.*
2) $E_{k2} = W_{net}$	
3) $E_{k2} = \|F_{net}\|\|\Delta d\| \cos\theta$	
4) $E_{k2} = \|ma\|\|\Delta d\|$	
5) $E_{k2} = \|ma\|\|(v_2^2 - v_1^2)/2a\|$	
6) $E_{k2} = \|ma\|\|v_2^2/2a\|$	
7) $E_{k2} = \|m\|\|v_2^2/2\|$	
8) $E_{k2} = ½mv_2^2$	

The *kinetic energy* of an object is the energy stored in the moving object. The amount of kinetic energy can be found from the expression $E_k = ½mv^2$. Where *v* is the instantaneous velocity of the object at the moment in time you are interested in. The value of the kinetic energy **does not** depend on the object's direction of motion – energy is a scalar quantity. Remember, to get a result in joules, make sure you use units of kg and m/s in this equation.

SPH3U: Changes in Gravitational Energy

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

When objects move vertically energy flows in or out of Earth's gravitational field. Let's follow this transfer and learn how to predict the motion of the system.

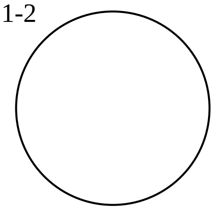
A: The Ball Drop and Kinetic Energy

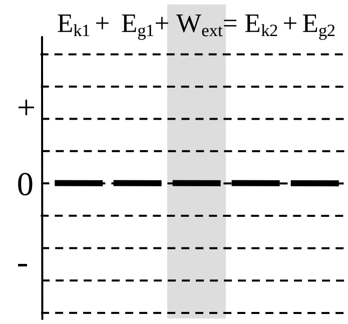
You will drop a basketball through a displacement of your choice (between 0.5 and 1.2 m) and examine the energy changes.

1. **Represent.** Draw a sketch of a ball falling and indicate two moments in time 1 and 2 at the start and end of its trip down (just *before* it hits!) Label the two vertical positions y_1 and y_2. Complete the energy-flow diagram and bar chart for the **earth-ball** system.

Sketch

1-2





Our bar charts are helpful tool for thinking about changes in energy. They are also helpful for construction an equation that relates the energy of a system at two moments in time. The total energy of a system at one moment plus any changes equals the total energy of a system at another moment: $E_{T1} + W_{ext} = E_{T2}$. This is called a *work-energy equation* for the system. The bar chart helps us to decide which energies to include in each total. If a particular energy is zero, we don't bother including it.

2. **Represent.** Construct a work-energy equation for the earth-ball system.

3. **Calculate.** Use the expression for kinetic energy ($½mv^2$) and the expression for gravitational energy (mgy) and substitute these into your equation from the previous question. Be sure to use the labels "1" and "2" where needed.

4. **Calculate.** Use your new equation and an important measurement to find the speed of the ball just before it reaches the ground.

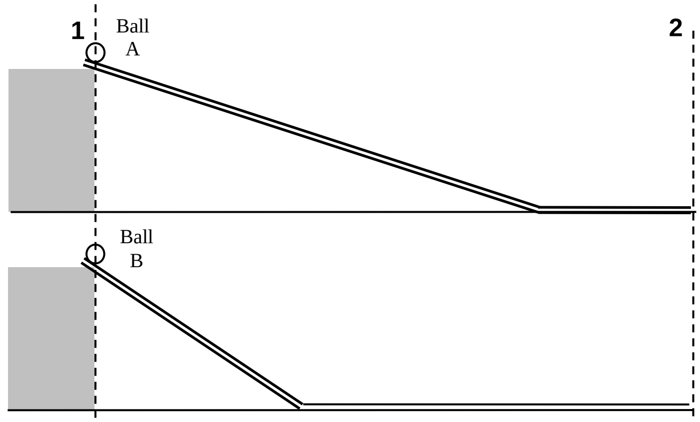
5. **Test.** Use the motion detector to measure the speed of the ball just before it hits the ground. Do the results agree with your prediction?

Gravitational and kinetic energy are two examples of *mechanical energy*. The total mechanical energy of a system will remain the constant as long as there are no external forces acting on the system and no frictional forces resulting in thermal energy.

6. **Reason.** Keeping in mind the assumptions we use in our model of energy flow, was the system total of mechanical energy constant during the drop of the ball? Explain.

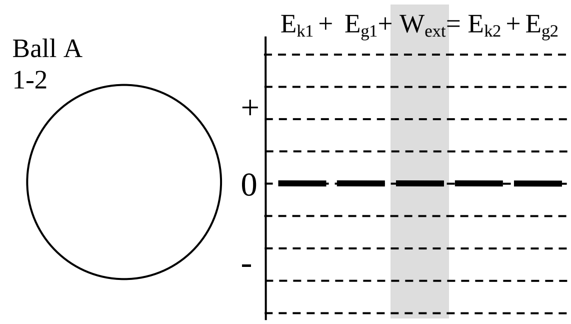
B: The Ramp Race

Your teacher has two tracks set up at the front of the class. One track has a steep incline and the other a more gradual incline. Both start at the same height and end at the same height. Friction is very small and can be neglected. There are two important events: (1) Ball A and B are released, (2) Each ball reaches the end of the track.

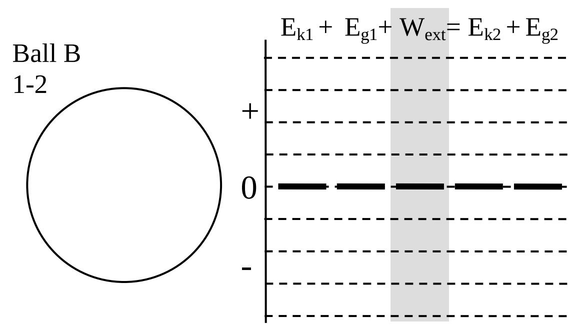


1. **Reason.** What energy changes take place as the ball travels down the incline?

2. **Represent.** Complete an energy flow diagram and an energy bar chart for each ball for the interval 1-2. **System = Ball, Earth**



3. **Explain.** Describe and explain any similarities between the two sets of diagrams.



4. **Predict.** Use your energy bar chart to predict which ball will have the greater speed at moment 2. Explain.

5. **Observe.** (*as a class)* Record your observations when: (a) the two balls are released at the same time

   and (b) when they reach the end of the track at the same time.

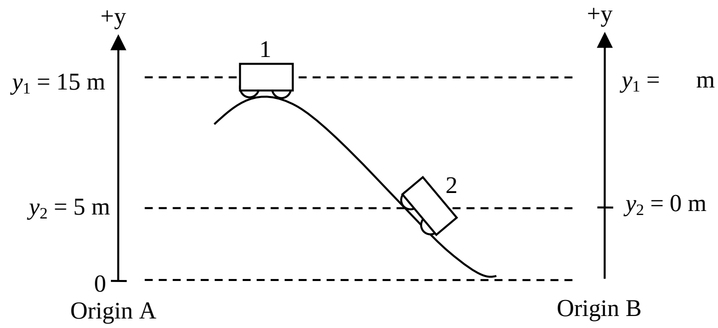
6. **Reason.** Albert says, "I don't understand why ball B wins the race. They both end up traveling roughly the same distance and ball A even accelerates for more time! It should be faster!" Based on your observations and understanding of energy, help Albert understand.

The amount of energy stored in, or returned from the gravitational field **does not depend on the path** taken by the object. It only depends on the object's change in vertical position (displacement). The property is called *path independence* – any path between the same vertical positions will give the same results. This is a result of the fact that gravity does no work on an object during the horizontal parts of the object's motion.

SPH3U: Changes in Gravitational Energy Homework Name:

A: Comparing Vertical Origins

The value for the gravitational energy depends on the choice of the vertical origin. If two people choose a different vertical origin, will their calculations predict different things? Let's see!

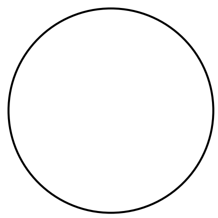


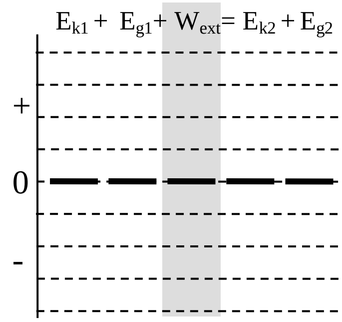
A 100 kg cart rolls down a curving track. It starts from rest at the top. We will examine two moments in time: (1) at the top of the track and (2) part way down.
System = cart, Earth

1. **Calculate.** Find the value of y_1 for Origin B.

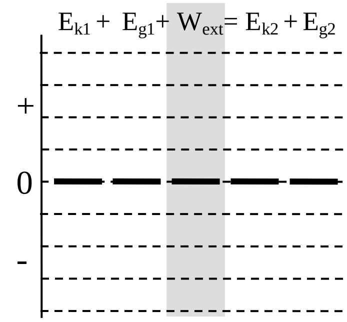
2. **Represent.**
   (a) Draw an energy bar chart for the two moments in time for each origin.
   (b) Draw one energy flow diagram.
   (c) Construct a work-energy equation for the system based on each origin.

1-2





Equation:



Equation:

3. **Calculate.** Complete the chart below. Calculate the gravitational energies of the system according to each origin. Use these energies to determine how much kinetic energy and speed the cart has a moment 2.

	E_{g1}	E_{g2}	E_{k2}	v_2
Origin A				
Origin B				

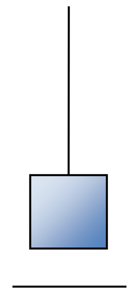
4. **Explain.** Use both the calculations and the bar charts to explain why the choice of vertical origin did not affect the results of the calculation.

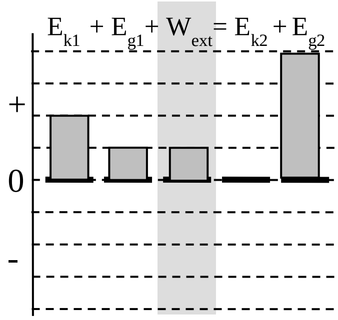
Only *changes* in gravitational potential energy have a physical meaning. The exact value of the gravitational potential energy at one position **does not** have a physical meaning. That is why we can set any vertical position as the origin. The vertical displacement of the object does not depend on the choice of origin and therefore the *change* in gravitational potential energy does not depend on it either.

Answer: v_2 = 14 m/s

SPH3U: Conservation of Energy Homework Name:

1. **Reason.** A block is attached to a rope so you can raise or lower it vertically. An energy bar chart illustrates the energies at two moments in time while it is being raised or lowered.
   (a) Use the bar chart to explain what is happening to the block. Hint: compare the kinetic energies to describe the speed. Compare the gravitational energies to describe the vertical positon.
   (b) Draw and energy flow diagram and write the work-energy equation for each interval.

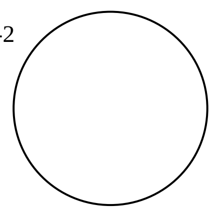




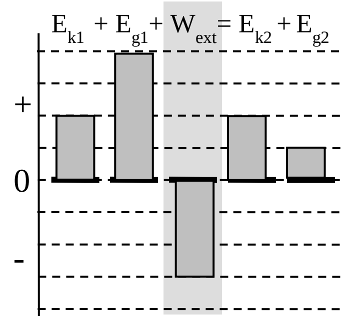
Explain:

Flow:

1-2



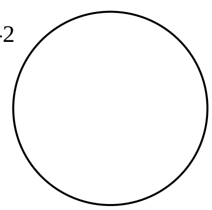
Work-Energy Equation:



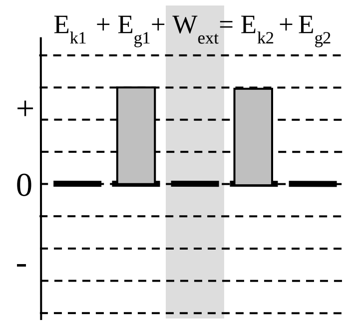
Explain:

Flow:

1-2



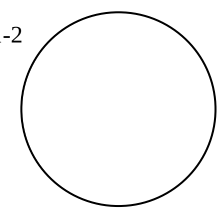
Work-Energy Equation:



Explain:

Flow:

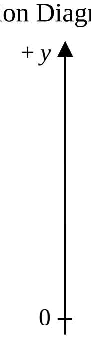
1-2

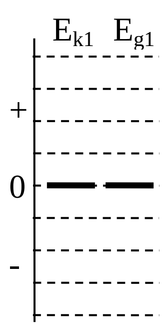


Work-Energy Equation:

2. **Represent and Calculate.** You throw a 200 g ball upwards. It leaves your hand with a speed of 10 m/s. We choose a vertical origin at the vertical position where the ball is released from your hand. We examine three moments in time: (1) it leaves your hand, (2) it is half way up, and (3) it is at its highest point.
   (a) Draw a motion diagram and label these moments.
   (b) For each moment in time, complete an energy bar chart for the earth-ball system.

Motion Diagram

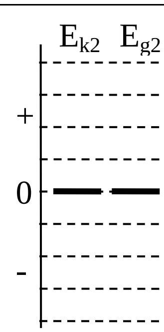




E_{k1} =

E_{g1} =

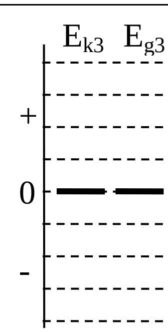
E_{T1} =



E_{k2} =

E_{g2} =

E_{T2} =



E_{k3} =

E_{g3} =

E_{T3} =

   (c) Calculate the energies at each moment and find the total energy of the system. Show your work below.

SPH3U: The Conservation of Energy

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

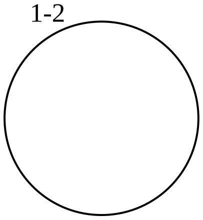
A: The Behemoth

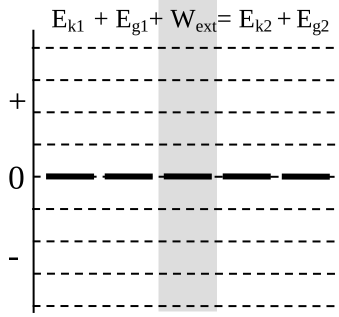
A recent rollercoaster at Canada's Wonderland is called "The Behemoth" due to its 70.1 m tall starting hill. Assume the train is essentially at rest when it reaches the top of the first hill. We will compare the energy at two moments in time: 1 = at the top of the first hill and 2 = at ground level after the first hill.

1. **Represent.** Choose a zero point for gravitational energy. Label on the photo the vertical positions y_1 and y_2.

2. **Represent.** Draw an energy bar chart and flow diagram for the earth-train system. Write down a work-energy equation that relates the energies of the system at moment 1 with moment 2. Only write down the energy terms that are not zero.

1-2





Work-Energy Equation

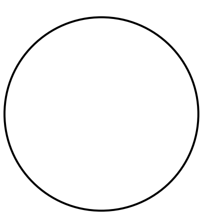
3. **Calculate.** Use the energy equation to find the speed of the rollercoaster at moment 2 in km/h.

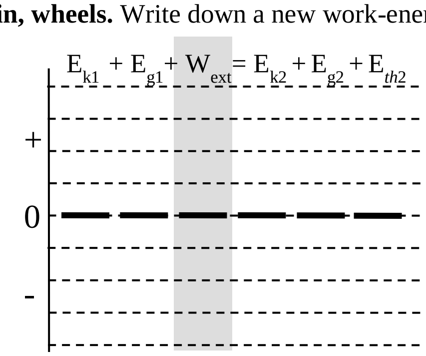
4. **Reason.** The official statistics from the ride's website give the speed after the first drop as 125 km/h. Is our model giving a reliable result? What assumption in our model might be faulty?

When two objects slide against another, energy can be transferred into *thermal energy* (E_{th}) due to a friction interaction. The two sliding objects will warm up, which means the thermal energy is shared between them. For this reason, when a friction interaction causes a transfer of energy **we will always include the two sliding objects as part of our system.** When we do, we can describe the increase in the thermal energy of the system using the expression: $E_{th} = F_f \Delta d$, where Δd is the **distance** the object slides.

5. **Represent.** Draw a new energy storage bar graph and an energy flow diagram that takes into account the effects of friction. **System = earth, train, wheels.** Write down a new work-energy equation.

1-2



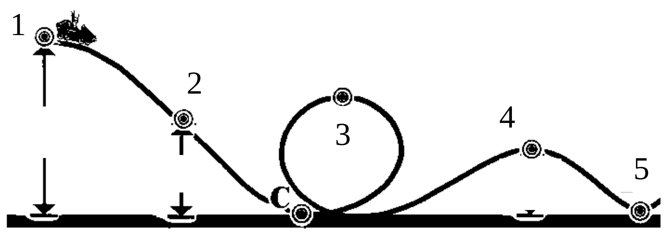


Work-Energy Equation

6. **Calculate.** Use the train mass, $m_t = 2.7 \times 10^3$ kg to determine the amount of thermal energy at moment 2. Hint: which velocity value should you use for E_{k2}?

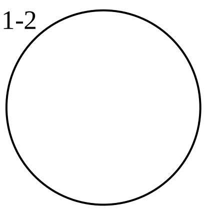
B: The York Mills Flyer

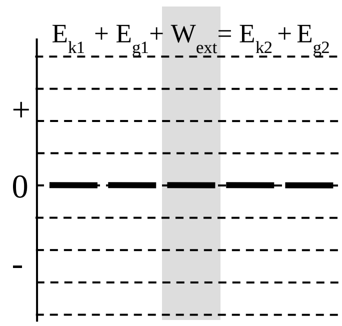
Rumour has it that a rollercoaster is going to be built in our school's courtyard. Plans leaked to the media show a likely design. The train starts from rest at moment 1 located 45 m above the ground. At moment 2 it is located 10 m above the ground. For all our calculations, we will assume that the force of friction is negligible.



1. **Solve.** Label the important vertical positions on the diagram. Complete the diagram and chart. Determine the rollercoaster's speed at moment 2.

1-2

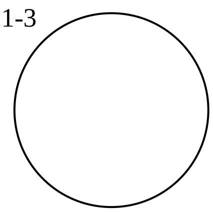


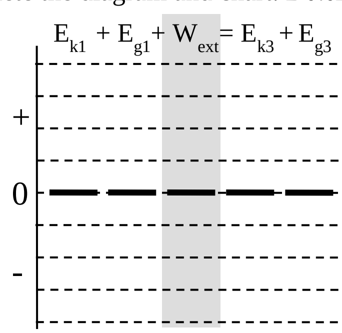


Equation

2. **Solve.** Label the important vertical positions on the diagram. Moment 3 is the top of the loop-de-loop and is located 17 m above the ground. Complete the diagram and chart. Determine the rollercoaster's speed at moment 3.

1-3





Equation

The loop-de-loop involves some very complicated physics, the details of which are much beyond high school physics. Yet using energy techniques, we did not have to consider those complications at all! When the total mechanical energy of a system remains constant (no losses to friction), we can relate the total mechanical energy at one moment in time to that at any other moment *without having to consider the intermediate motion – no matter how complex*. Wow!

SPH3U: Power

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Winning a race is all about transferring as much energy as possible in the least amount of time. The winner is often the most *powerful* individual.

Power is defined as the ratio of the amount of energy transferred (ΔE) to the time taken (Δt): $P = \Delta E / \Delta t$. If that energy transformation is done through work, then $\Delta E = W$. The S.I. unit for power is the watt (W) where 1 watt of power means 1 joule of energy transferred per second of time (1 W = 1 J/s).

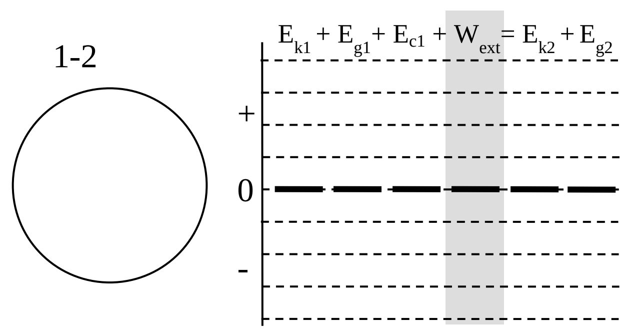
A: The Stair Master

Let's figure out your leg power while travelling up a flight of stairs. We chose two events: (1) at rest at the bottom of the stairs, and (2) at rest at the top of the stairs.

1. **Reason.** Describe the energy changes that take place between events 1 and 2. E_c represents an amount of chemical energy stored in your muscles.

2. **Represent.** Complete an energy flow diagram and bar chart for the interval 1-2.

3. **Reason.** To calculate your *power*, you need to identify the change in energy, ΔE, that you will use. There are two important changes in energy in this situation: ΔE_c and ΔE_g. Which of these best represents a change in energy involved with *your* power?



4. **Represent.** Draw a sketch showing events 1 and 2. Label the important vertical positions. Label the quantities you will measure to find your power.

*** check with your teacher before gathering any equipment ***

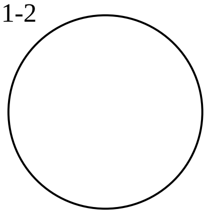
5. **Observe.** Gather the equipment you will need for your measurements. Travel up a flight of stairs at a modest pace (but don't run, we don't want you to fall!) Record your measurements on your diagram.

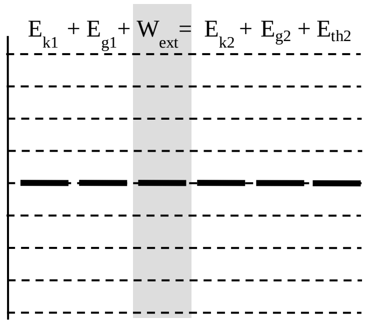
6. **Calculate.** Compute your leg power in watts (W) and horsepower (hp) where 1 hp = 746 W. Show your work. How does this compare to your favourite car? (2016 Honda Civic = 158 hp)

B: Back to the Behemoth!

1. **Solve.** The trains on the Behemoth start at rest from at the loading platform (10 m above the ground) and are lifted to the top of the first hill by a motor in 67 s. At the top, 70.1 m above the ground, the train has a speed of 1.7 m/s. Along the way, the train experiences a frictional force of 3724 N. The train (including passengers) has a mass of 2700 kg. How powerful should the motor be to accomplish this task? Complete the energy diagram and bar chart below**. System = earth, train, wheels.**

1-2



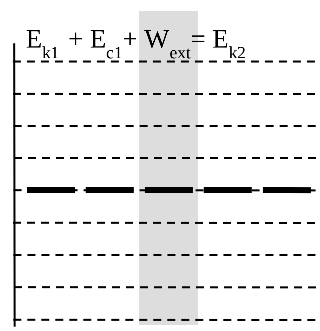


Work-energy equation:

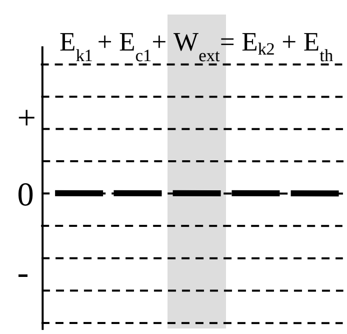
C: He's Got the Power

1. **A Powerful Run.** Usain Bolt is able to reach a top speed of 44.72 km/h by the 65-m mark of a 100-m race. It took him about 6.3 seconds to reach that top speed. He has a mass of 96 kg. He accomplishes this by transferring energy stored in chemicals in his muscles into energy of motion. We will explore this using two models.

   (a) **Model #1: 100% Efficient.** Let's begin by assuming that all the energy used by Bolt is transferred to kinetic energy. Draw an energy bar chart showing the transfer of energy. What is his power while he is accelerating to his top speed?



   (b) **Model #2: Thermal Losses.** Unfortunately, the human body is not so efficient as our chart above suggests. Quite a bit of energy chemical is transferred to thermal energy. Let's assume that his muscles are 50% efficient at transferring chemical energy to kinetic energy. Draw the bar chart for this revised situation. What is his power now?



2. **Energy Consumption**. Which consumes more energy, a 1.2 kW hair dryer used for 10 minutes or a 10 W night light left on for 24 h?

Answers: #1(a) 1180 W, (b) 2350 W, #2 night light!

SPH3U: Energy Challenge

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

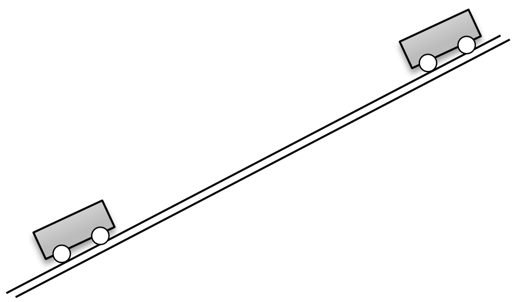
An inclined dynamics track is set up at the front of the room. A cart on the track has a friction pad attached underneath. You get to choose where along the track to release the cart. Your challenge is to predict the speed of the cart after it is released, when it reaches the 2.0 m mark near the bottom of the track.

1. **Represent.** Complete part A of the solution process below. For the moment, use symbols for any given quantities that you will need to know to solve this problem. Label the important vertical positions. Don't rush up and measure anything yet.

2. **Measure.** Your group should finish all of part A except for the given quantities. Now, measure any quantities you think will be important for solving this problem. Record your measurements (with uncertainties!) as the givens for this problem. Your teacher will give you a value for the force of friction.

A: Pictorial Representation

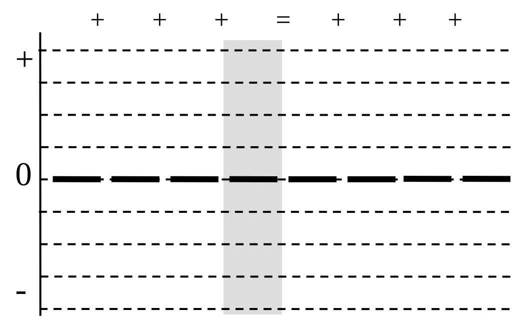
~~Sketch showing events~~, describe events, coordinate system, label givens & unknowns with symbols, conversions



3. **Reason.** You need to choose the system objects for this problem. Which objects are involved in transfers of energy? Which should we include in our choice of system?

B: Physics Representation

Energy bar chart, flow diagram, events



4. **Describe.** In the word representation, describe how the cart is moving. Describe any energy flows that you have illustrated in your energy flow diagram.

C: Word Representation

Describe motion, describe energy flows, estimated result (no calculations)

D: Mathematical Representation

Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

There are two ways to approach the math work in energy problems like these:

(1) **Compute each energy value.** This approach involves a separate calculation for each energy value involved in a problem. This can be helpful in lengthy problems. The downside is this approach adds a lot of steps, work, and time. There are more opportunities to make simple arithmetical mistakes.

(2) **Construct one equation and isolate.** This approach involves constructing one work-energy equation and working with the symbols to isolate the unknown quantity you are interested in. This is the preferable technique, but there are occasions when the equation might be complicated and messy, making the first approach easier. In this problem, try to isolate v_2^2 and then substitute values.

E: Evaluation

Answer has reasonable size, direction and units? Explain why.

5. **Test and Evaluate.** Once you have completed your full solution (including part E), use the equipment at the front to test your result. Record your results here. Does your model of this problem successfully predict the results? Explain.

SPH3U: The Flow of Electricity

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

What happens when we flick on the light switch at home? In this investigation, we begin to explore how electrical circuits work.

A: Building a Model for the Flow of Electricity

1. **Observe.** (*as a class)* Your teacher will connect a small piece of steel wool into an electric circuit (don't try this at home!). Describe what you *observe* (what you can see).

2. **Crazy Guesses.** (*as a group*) With your group, discuss what you think is happening inside the wool, wires, and power supply. Don't worry about being right – just come up with some ideas!

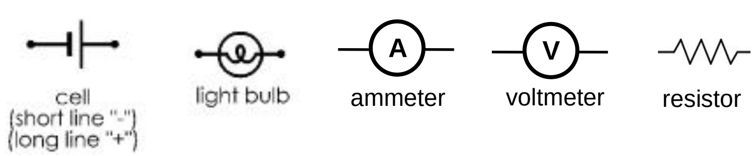
B: How Many Ways Can You Light a Bulb?

You will need a battery, a light bulb and a single wire.

1. **Explore.** In the chart below, connect the three items together in a variety of ways. Draw a visual **sketch** (not a circuit diagram!) of **two** arrangements that cause the bulb to light on the left and two arrangements that don't on the right.

Bulb lights	Bulb doesn't light

A circuit diagram is a simplified drawing of an electric circuit. Instead of drawing realistic pictures of the parts in a circuit, we use simple symbols like the ones shown below. All wires are drawn using straight lines and right angle corners.



2. **Represent.** Draw a circuit diagram for each design you came up with in question A#1. Be sure to use a ruler.

Bulb lights	Bulb doesn't light

3. **Find a Pattern.** According to your circuit diagrams, what conditions are necessary for the bulb to light? How are those conditions **not** satisfied in the circuits that don't light up?

A *closed* circuit is one in which an electric current can flow. An *open* circuit does not allow an electric current to flow.

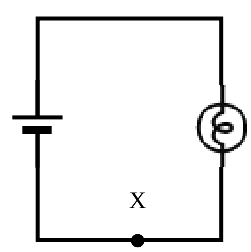
4. **Apply.** Which of the circuit diagrams you drew represent open and closed circuits? Label the circuits above as open or closed.

C: Investigating Current Flow

The flow of electricity is called the *electron current*, or just simply, the *current*. We picture this as the movement of negative charges (the electrons) through the electric circuit. An *ammeter* is a tool that measures the size and direction of the current that flows through it. To measure the current travelling through one point in a circuit, simply "insert" the ammeter into that location in the circuit. Electric current is measured in units of *amperes* (A) or amps for short, or sometimes milliamps (mA) for small currents.

1. **Represent.** Examine the circuit shown to the right.
   (a) Label the positive and negative terminals of the battery in the circuit diagram.
   (b) Draw an arrow to show the direction the electron current will move as it leaves the negative terminal of the battery.

2. **Represent.** We want to measure the amount of current flowing through point X in this circuit. Draw a revised version of this circuit with an ammeter inserted at point X.

Original Circuit	Revised Circuit with Ammeter
	

3. **Test.** Build this circuit. Record the current measurement of the ammeter beside the symbol in your circuit diagram. (Include the units!) Please disconnect the circuit when you are not making your measurements! Save the batteries.

4. **Test and Explain.** Reverse the leads going into and out of the ammeter. Observe the meter reading. Why do you think the reading appears different?

Electron current is a flow or movement of electrons (charge) during an interval of time. To calculate electron current, we use the equation: $I = Q/\Delta t$, where I is the current measured in *amps* (A), Q is the number of electrons measured in units of *coulombs* (C) and Δt is the interval of time during which the charge flows and is measured in seconds. Due to the incredible number of electrons moving in most circuits, the unit of one coloumb represents a very large number of charges (1 C = 6.241×10^{18} charges!). One amp of current means one coulomb of charge flowing past a point every second.

5. **Calculate.** Use the ammeter reading you made to calculate:
   (a) the number of coloumbs of charge that flow through point X in one second of time.

   (b) the number of electrons that flow through point X in one second of time.

SPH3U: The Flow of Electricity Homework Name:

1. **Calculate**. Your cell phone charger supplies 2.0A of current to your phone. You plug in your phone overnight (8 hours). How much charge does the charger move through your phone?

A: Pictorial Representation	D: Mathematical Representation
~~Sketch~~, ~~coordinate system~~, ~~describe events~~, label givens & unknowns with symbols, conversions	Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

2. **Calculate**. Many modern household circuits are protected by a ground fault circuit interrupter (GFCI). The current flowing through a circuit in your home is monitored by the GFCI. If it detects a loss of current (which happens when someone gets a shock), it quickly opens the circuit, stopping the flow of electricity. In one situation, a person accidentally touched a live wire in a home circuit. As a result, 30 mA of current begins to flow through their body. The GFCI open the circuit (stopping the current) after 25 ms. How many electrons travelled through the person's body?

A: Pictorial Representation	D: Mathematical Representation
~~Sketch~~, ~~coordinate system~~, ~~describe events~~, label givens & unknowns with symbols, conversions	Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

3. **Calculate.** You rub a balloon on your head and you create a build-up of electric charge on the balloon surface. You touch the balloon to a door knob and see (and hear!) a tiny spark as the charges move from the balloon to the door knob. You estimate that the balloon had a charge of 5×10^{-8} C and the charges moved to the knob in very little time, about 1 ms. What was the current during the spark?

A: Pictorial Representation	D: Mathematical Representation
~~Sketch~~, ~~coordinate system~~, ~~describe events~~, label givens & unknowns with symbols, conversions	Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

SPH3U: Models of Current Flow

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

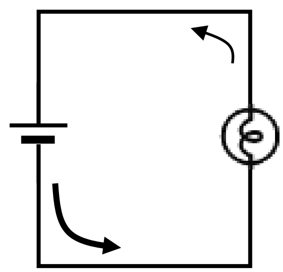
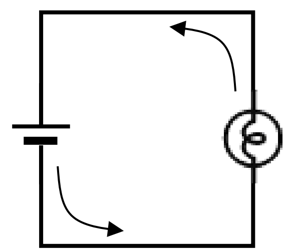
If we ask grade 9 students to explain what happens to electron current as it moves through a circuit, two common explanations or hypotheses are often given. We will explore and test these hypotheses.

A: Testing Current Models

1. **Predict.** Science works by testing the predictions made using different models or hypotheses. We choose to make measurements that will hopefully support or refute the hypotheses.

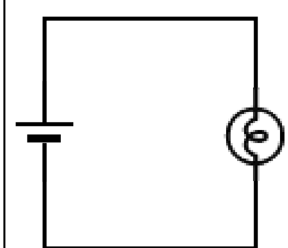
    (a) In order to test the two hypotheses, we need to make current measurements. On each diagram, draw an ammeter at each point in the circuit where you would like to make a measurement.

    (b) Make a prediction for the current readings of each ammeter you have drawn. Use words like: "smaller", "larger", "the same", or "none". Record the prediction beside each ammeter.

Hypothesis A: **"Some electrons are used up"** The direction of the current will be in the direction shown, but there will be little or no current after the bulb.	**Hypothesis B:** **"All electrons make the full trip"** The direction of the current will be as shown, and it will be the same in both wires.
Predictions A: 	**Predictions B:** 

2. **Test.** Build the circuit and connect the ammeter at each point to make the measurements you have chosen. Draw an ammeter for each measurement in the observation circuit to the right. Record your measurements beside each ammeter.

Observations:



3. **Evaluate.** Use the results of your measurements to decide which hypotheses are refuted and which are supported. Write "<u>Refuted</u>" or "<u>Supported</u>" in the centre of each circuit diagram. On a whiteboard, record the result for each hypothesis.

4. **Summary (*as a class*).** What happens to the number of charges (electrons) moving along one path of a circuit?

B: Where Does Current Come From?

If we ask grade 9 students where the electrons moving in a circuit come from, most will say that the electrons come from the battery. We will test this hypothesis. Careful calculations and measurements show that the electron current in a closed circuit similar to ours will travel through the wire at a speed of about 0.23 mm/s.

1. **Predict.** Hypothesis: "All the electrons from the battery". Use the speed to predict how much time it would take for the electron current to travel from the battery to the bulb in your circuit. (Hint: you will need to make a measurement to complete this prediction.)

2. **Evaluate.** Do your observations from your earlier experiment (or flicking a light switch at home) support or refute the "current from the battery" hypothesis?

3. **Crazy Guess**. Where do you think the electrons moving in your circuit come from?

C: Learning the Ropes

Your teacher has a long loop of rope that all the students of the class will hold up, forming a large ring around the classroom. The rope is a model for the flow of electricity in a circuit. After the demonstration and discussion led by your teacher, answer the following questions about this model.

1. **Reason.** Complete the chart below by explaining what each part of the rope model represents about an electric circuit.

The rope itself (or each particle of the rope).	
The moving rope.	
Students holding the metal rings.	The wire.
Student holding the rope tightly.	
Student pulling the rope.	

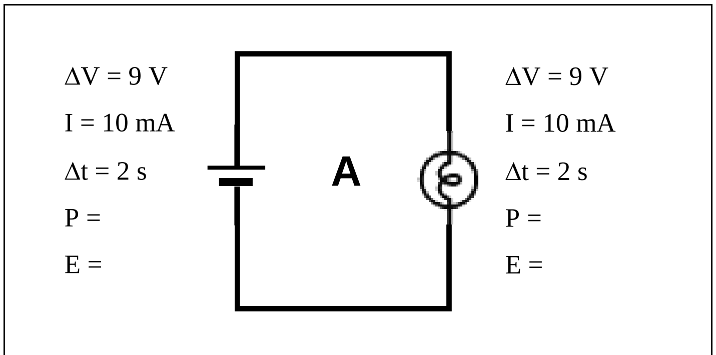
2. **Reason.** According to the rope model, where are the electrons located before we "turn on the battery"?

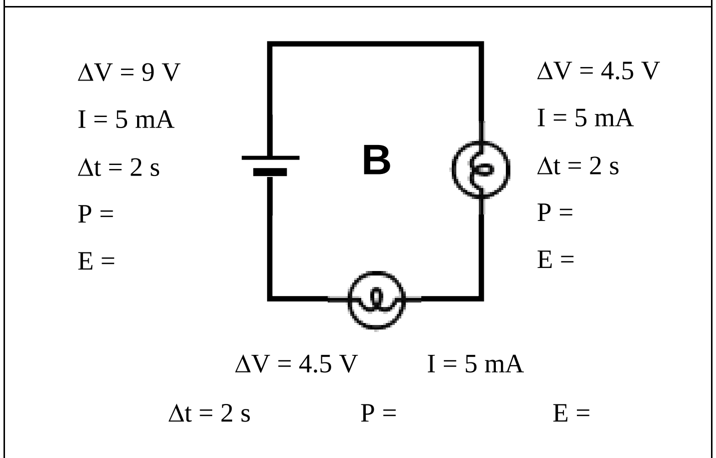
3. **Reason.** In addition to moving the rope, the student pulling the rope transfers something to the student holding the rope tightly. What is being transferred and what evidence supports your hunch?

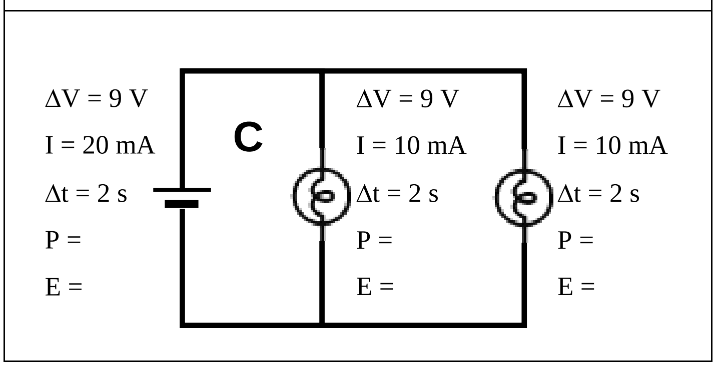
4. **Reason.** According to the rope model of an electric circuit, what role does a battery play in an electric circuit (what does it do)? What role does the bulb play?

SPH3U: Electric Energy Homework Name:

Three electric circuits are shown below. The first is the simple circuit we have been exploring in class. The other two are two-bulb circuits that will help us explore the ideas of energy in electric circuits.







1. **Describe.** Describe what happens to the energy of the system of electrons in circuit B as they travel the complete loop of the circuit.

2. **Represent.** Draw a voltage graph for circuit B. Label each interval of the graph as “battery”, “wire” or “bulb”.

3. **Calculate.** Calculate the power and the energy use of each bulb and battery in the three circuits after two seconds of time. Record your results beside each circuit element.

4. **Reason.** We decide to keep the three circuits running for a longer period of time. Which quantities will stay the same and which will change? Explain.

5. **Reason.** The three batteries will eventually “run out”. Which quantity should you compare amongst the three batteries, to decide which will last the longest? Explain.

6. **Reason.** Rank the three batteries according to how long they will last in order from longest to shortest. Justify your ranking.

7. **Predict.** Which quantity do you think the brightness of a bulb depends on? Rank the bulbs in the three circuits from brightest to dimmest. Justify your ranking. We will test these predictions next class!

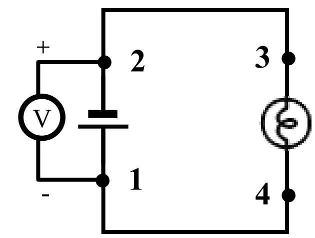
SPH3U: Electric Energy

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

We are left with a mystery: we know the electron current is not "used up" in the bulb, so why does the bulb light up? Is something else getting "used up"?

A: Looking for Patterns with Energy

A *voltmeter* measures the change in energy of a unit of charge as it moves between two points in a circuit. To use a voltmeter, you must connect the meter's two leads to two different points in a circuit. In contrast, an ammeter is inserted at one point in a circuit (connected in *series*). A voltmeter connects across two points, without disconnecting the original circuit (connected in *parallel*). This allows the voltmeter to measure a change in **energy** between those two points.



1. **Test.** Construct the simple circuit we used last class. Connect the voltmeter across different parts of the circuit with the pair of leads connected at the points numbered in the chart below. If the meter has difficulty measuring a value, try reversing the leads. Complete the chart.

Voltmeter leads connected at points	Part of circuit charge moves through	Observed meter reading
1 and 2		
2 and 3		
3 and 4		
4 and 1		

2. **Record.** Write the results of your chart on a whiteboard and place it along the side of the class, facing away. Record your reading carefully!

3. **Explain**. According to your measurements, what is happening to the amount of energy carried by the electrons moving in this circuit between each pair of points?

4. **Reason.** Based on our observations, we will make an assumption when we work with wires in grade 11 physics. Complete the box below describing that assumption.

In our model of electric circuits, we will always make the *ideal wire assumption*:

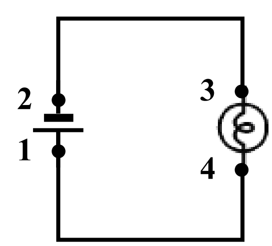
B: Energy in Electric Circuits

In a circuit, the system we study is a system of electrons. A *source*, like a battery, adds energy to the system of electrons. A *load*, like a bulb, removes energy from the system of electrons. Energy stored in this system is called *electrical* energy.

Let's follow a group of electrons during their trip around a simple circuit and keep track of the energy transfers. There are four important positions labelled in the circuit diagram below.

1. **Represent.** For each interval between two points, decide if the energy of the system of electrons increases, decreases, or stays the same.

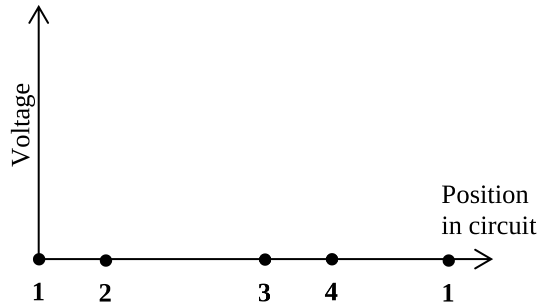
Interval	System energy
1 - 2	
2 - 3	
3 - 4	
4 - 1	



A *voltage graph* represents the energy transfers that take place along one path in a circuit. The vertical axis represents the voltage of the system of electrons and the horizontal axis represents the position of the electrons along the circuit. For convenience, we will choose the starting energy to be zero (like we did with gravitational energy).

2. **Represent.** Draw a voltage graph for the circuit on the previous page. The exact values are not important, but the ideas are. Label each interval with words describing each part of the circuit.

3. **Reason.** The position marked “1” appears twice in the graph. Explain why. How should the voltage values at the “1”s compare?



In a real circuit, there are many, many electrons moving and transferring energy. As a result, we will track the energy transfers for each coulomb of electrons (6.241×10^{18} electrons!). The amount of energy transferred by each coulomb is the definition of *voltage* (sometimes called the *electric potential difference*). 1 volt is defined as a change in electrical energy of 1 joule for each coulomb of charge, or 1 V = 1 J/C. This is represented by the equation: $\Delta V = \Delta E/Q$.

4. **Explain.** A 9V-battery is connected to a circuit. When electrons move through the battery, they gain energy. Explain in a simple way how much the electric energy changes when:
   (a) One coulomb of electrons moves through the battery

   (b) Half a coulomb of electrons moves through the battery

C: You’ve Got the Power

A common way of describing the use of energy is power. Recall from the energy unit, that power can be found from the equation: $P = \Delta E/\Delta t$.

1. **Calculate**. Suppose you had your circuit switched on for 10 s, the current through the bulb was 80 mA and the voltage drop 2.8 V. Calculate the amount of energy used by the bulb. Calculate the power of the bulb.

2. **Calculate.** Repeat the calculation you have just done, but using symbols only! The voltage is ΔV, the quantity of charge Q, the current I and the time Δt. Use these to create the official equation for electric power. (Did you need to know the time?)

Power used by an element in a circuit:	**Units of power:**

SPH3U: Current and Voltage Laws

We have started to notice some patterns for how voltage and current behave in a circuit. Now we are ready to look for rules or laws that describe these patterns.

A: Using the Circuit Simulator

We began this unit building real circuits using real materials. Now we will use a simulator to allow us to quickly construct and test new circuits. You can find the simulator by googling "PhET DC circuits".

1. **Build.** Use the simulator to construct the three circuits from the "Electric Energy Homework". Make sure each person in your group has a chance to build a circuit. Don't erase them when you are done.

2. **Test and Evaluate.** You made some predictions about the brightness of the different bulbs. Describe your observations from the simulator. Do your observations support or refute our predictions?

B: Testing Ideas About Current

We want to explore what happens when current reaches a junction point. A junction point is a point in a circuit where wires join together. For example, a single wire might split off into two wires, or three wires might come together into one wire.

1. **Reason.** Imagine you are trying to explain to a grade 9 student what happens when electric current reaches a junction point (one wire splits into two). Rather than explaining using electrical terms, you want to explain using an analogy (a more familiar model). Describe what happens at this junction point by explain what happens to water flowing through pipes.

2. **Hypothesize.** Explain this situation again using electrical ideas. You are creating a hypothesis, a physical explanation for how current works in this situation.

3. **Prediction.** Which circuit that you have already built could be used to test your hypothesis? Choose one junction in that circuit and draw it. Make a prediction: if 1.8 A of current flows into the junction point …. Label your predictions beside each wire in your drawing. Draw an arrow showing the direction of current in each wire.

Prediction

4. **Test and Evaluate.**
   (a) Use the simulator to measure all the currents (using the non-contact ammeter tool is a convenient way of doing this).
   (b) If your prediction was correct, give it a check mark. If not, cross out the prediction and record the measured value.
   (c) Do these results support or refute your hypothesis?

5. **Predict.** What if the two bulbs were different? For example, if 1.1 A of current flows to one bulb, how much would flow into the other bulb?

6. **Test and Evaluate.** Right click on one bulb in your simulation and change its resistance (any change will do). Measure the current values. Do the results support or refute your hypothesis?

7. **Extreme Test.** When scientists think they have the right idea, they like to test it using extreme examples. Build a circuit that has a very interesting, unusual or complex junction point (make sure you can still see what's going on). Measure the current in each branch in and out of the junction point.

8. **Record.** On a whiteboard draw the junction point only. Show the branches going in and out. Record all your measurements along with arrows showing the direction of the current. Summarize the significance of your result. Place your whiteboard on the side of the room so everyone can see.

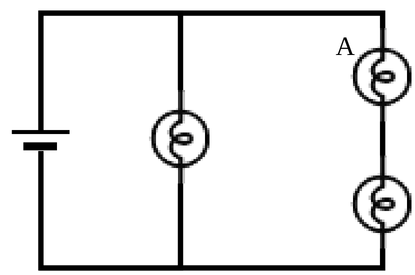
9. **Summary.** (*as a class*) Create a rule for the current in and out of a junction point.

Law for current at a junction.

C: Testing Ideas About Voltage

Voltage is a measurement of the gain or loss of energy as groups of electrons move through a circuit. When electrons move through a source, there is an increase of electric energy, which we call a *voltage rise*. When electrons move through a load, there is a decrease of electric energy, which we call a *voltage drop*. We will use positive values for both voltage rises and drops. A *loop* is a closed path through a circuit. We will focus on loops that follow the path in a circuit that an electron might take.

1. **Reason.** In the circuit to the right, use different colours to draw each possible path or loop that an electron can take through this circuit.



2. **Build and Test.** Construct this circuit in the simulator. To better understand the patterns, change the resistance of bulb A (right click). Measure the voltage rise or drop across each individual circuit element. Record these values beside each element in the circuit diagram.

3. **Hypothesis.** Follow an electron along each path of this circuit. Describe a pattern relating the voltage rise and to the voltage drop.

4. **Build.** Design an interesting circuit that has multiple loops using two or three batteries and two or three bulbs. Neatly draw your circuit.

5. **Test.** Use the simulator to help identify the loops in the circuit (follow the moving electrons!). For up to three loops in this circuit, measure the voltage values and record those values beside the elements in your diagram.

6. **Evaluate.** For each loop you chose, show the voltage rise and drop in the space below. Do your results support or refute your hypothesis.

Test Circuit

7. **Summarize.** Describe a rule for the voltage rises and drops a loop of a circuit.

Law for voltage in a loop.

8. **Test and Evaluate.** Does the law for current at a junction hold for your new circuit? Make measurements and explain.

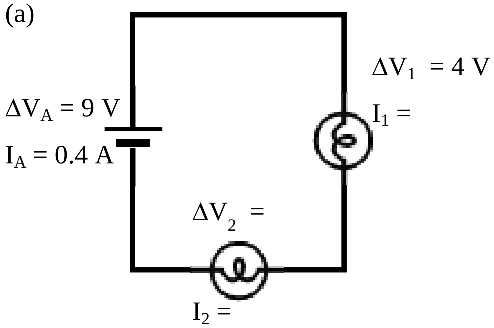
SPH3U: Current and Voltage Law Homework Name:

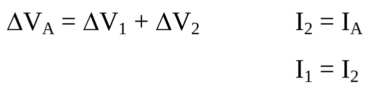
1. **Represent.** For each loop in the circuits below, use the voltage law to write an equation that relates the voltage rise and drops of that loop. An example is given with the first circuit.

When we perform calculations for circuits, it is important that **your work is clear** to any person reading your analysis. Always write a complete equation using symbols. Isolate your unknown quantity. Substitute your values and calculate the result.

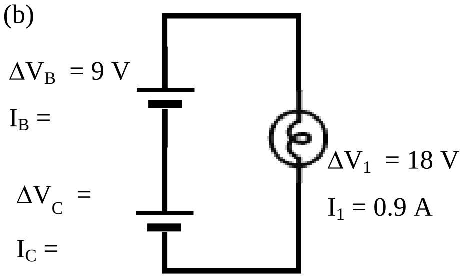
2. **Calculate.** Use the equations you created to find any missing voltage values.

(a)

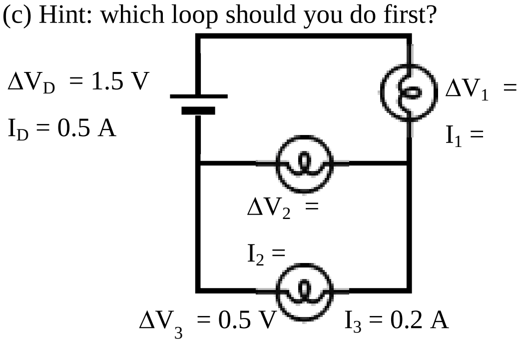




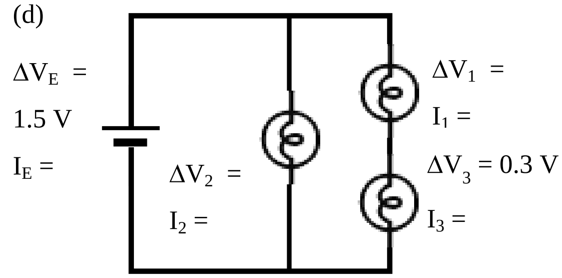
(b)



(c) Hint: which loop should you do first?



(d)



3. **Represent.** For each missing current value, choose a point in the circuit just before or after that element. Use the current law to construct an equation describing the current flowing in and out of the point you have chosen. Two examples are given with the first circuit.

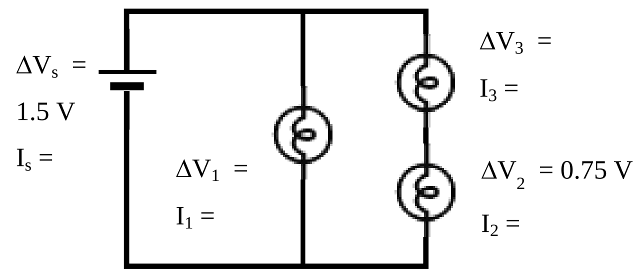
4. **Explain.** Imagine we follow the electrons that travel through the larger loop of the circuit in question #2d. Draw an voltage graph for that loop of the circuit. Label carefully each interval in the circuit as “battery”, “bulb 1”, “bulb 3”, or “wire”.

SPH3U: Resistance and Ohm's Law Homework   Name:

1. **Calculate.** A standard LED lightbulb in your home has a typical resistance of 1800 Ω. The electrical receptacles in the walls of your home provide a voltage drop of 120 V. What is the current flowing through the LED bulb?

A: Pictorial Representation	**D: Mathematical Representation**
~~Sketch~~, ~~coordinate system~~, ~~describe events~~, label givens & unknowns with symbols, conversions	Describe physics of steps, complete equations, algebraically isolate, substitutions with units, final statement of prediction

2. **Solve.** Each bulb in this circuit is identical and has a resistance of 37.5 Ω. Our goal is to find all the voltage current values for each bulb and the battery.



(a) **Explain.** What idea can we use to find the missing voltages?

(b) **Represent.** Write down a pair of equations **using symbols** that relate the voltage rise and drops in each loop.

(c) **Calculate.** Find each missing voltage value. Show your work. Write your results beside each bulb.

(d) **Explain.** What idea can we use to find the electron current flowing through each bulb (Hint: we know the voltage and resistance for each)?

(e) **Represent.** Write an equation **using symbols** that relates the current, voltage and resistance of each bulb.

(f) **Calculate.** Find the current values for each bulb. Show your work. Write your results beside each bulb.

A battery does not obey Ohm's Law. An ideal battery always provides the same voltage rise and has no internal resistance (zero resistance), no matter what the battery is connected to. We cannot use Ohm's law to relate the current and voltage of the battery.

(g) **Explain.** What idea can we use to find the amount of current flowing from the two branches in the circuit, into the battery?

(h) **Represent.** Write an equation **using symbols** that relates the currents into and out of the junction point.

(i) **Calculate.** Find the amount of electron current flowing into the battery. Write the results beside the battery.

SPH3U: Resistance and Ohm's Law

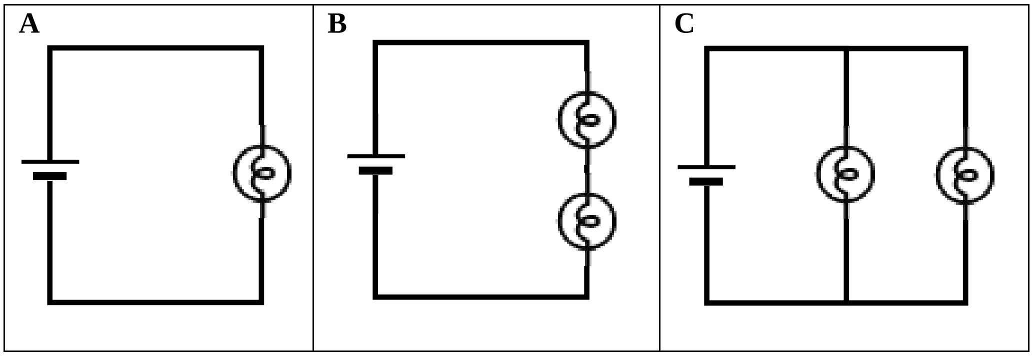
Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

We have explored current at junctions and voltage in loops. One thing we can't do yet is predict the amount of electron current that flows down a particular path. To do this, we need one more idea describing electricity: resistance.

A: The Idea of Resistance

Consider three simple circuits that we have seen before in your homework.

1. **Reason.** Rank the three circuits in order from least to greatest current flowing through the source. (You can peak at your earlier homework.)



2. **Explain.** The battery is identical in each of these circuits, yet different amounts of current flow through it. What does this suggest about the "amount of resistance" each battery experiences when it tries to push the current?

3. **Explain.** Imagine each bulb is like a rough patch of road that cars (the charges) are trying to travel along. Use a traffic analogy to help compare the amount of current flowing through the battery in circuits A and B. Consider circuit A to be "normal" traffic.

4. **Explain.** Imagine each bulb is like a check-out counter at a grocery store. Use this analogy to compare the current flowing through the battery in circuits A and C.

5. **Summarize.** Create a simple rule describing what happens to the total resistance (the resistance the source "feels") when elements are connected in series and in parallel. You don't need to use any math.

Elements Connected in Series:

Elements Connected in Parallel:

When electrons move through a circuit, we can imagine them bumping into the metal atoms of the wire, bulb, or other circuit element. When they do, electric energy is transferred to thermal energy of the wire's atoms. This is a simple model for *electrical resistance*. Resistance is measured in units of *ohms* (Ω) and has a value that depends on the type of material the element is made from and its shape (like a wire's diameter and length).

B: Connecting Resistance to Current and Voltage

How is the amount of current affected by the resistance of a circuit element? Time to find out!

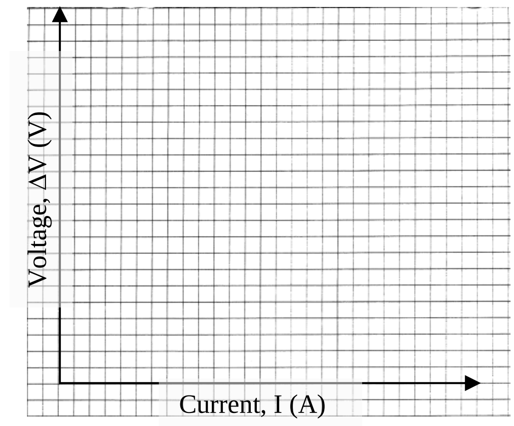
A *resistor* is a circuit element whose purpose is to add resistance to a circuit. The symbol for a resistor is: 

1. **Build.** Use the simulator to construct a simple circuit consisting of one resistor and one battery. Our goal is to measure the amount of current flowing through the resistor as we change the voltage of the battery.

2. **Crazy Guess.** We can think of the voltage as a measure of "how hard" the battery is pushing the charges. What pattern do you think we will find for the current as we change the voltage?

3. **Test.** Measure the current values as you change the voltage of the source (right click on the battery). Record your measurements in the table.

4. **Represent.** Plot a graph showing the relationship between current and voltage. To help make our next comparison, we will break with convention and **put voltage on the vertical axis.**



5. **Analyze.** Calculate the slope of the graph. Be sure to use physics symbols and units!

The slope of the voltage-current graph is the resistance, *R*, of the element.

6. **Represent.** Construct an equation for the line of this graph. Start with the familiar equation $y = mx + b$ from math class and translate it into physics by using the physics symbols of this graph. Record the final result in the box.

Ohm's Law:

The equation you have constructed is called *Ohm's Law* and relates the current and voltage for *ohmic* circuit elements that have a *linear* relationship between voltage and current. Resistors are a good example of this, but batteries are not!

7. **Interpret.** What does this equation tell us about current, voltage and resistance?
   (a) If voltage stays the same (same battery) but resistance increases (different resistor), the …

   (b) If the resistor stays the same (same resistor), but the voltage increases (different battery), the …

The resistance of a circuit element can be found by rearranging Ohm's law: $R = \Delta V/I$, where ΔV is the potential difference across the element and *I* is the current flowing through it. When the potential difference is measured in volts and the current in amperes, the unit of resistance is the *ohm* (Ω, the greek letter 'omega'). One amp of current flowing through an element with a 1 ohm resistance will lose 1 J of energy.

8. **Calculate.** In your "Electric Energy" homework you found the current and voltage values for the bulbs in a variety of circuits. Use Ohm's Law to find the resistance of each of the five bulbs in that homework. What do you notice?

Problem Solving Hint: You have now learned *four* (!) different ways to find a voltage or a current. You can use a basic definition ($\Delta V = \Delta E/Q$ or $I = Q/\Delta t$), you can use power ($P = VI$), you can use a voltage or current law ($\Delta V_{rise} = \Delta V_{drop}$, $I_{in} = I_{out}$), or you can use Ohm's Law ($\Delta V = IR$). When you approach a problem, always begin by looking at what quantities you already know, then choose a strategy.

SPH3U: Equivalent Resistance

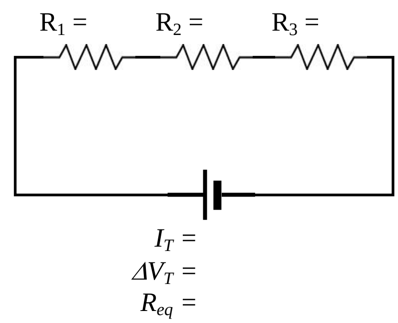
Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

The electrical circuits found in most electronic devices consist of many different elements combined in series and parallel *networks*. A network is just a part of a larger circuit that we focus our attention on.

It is very helpful to be able to figure out the combined resistance or *equivalent resistance* of a group of elements acting together. If we can find the equivalent resistance, we can think of that set of elements or *network* as if it was one thing with a resistance value equal to the equivalent resistance of the network. This is a very powerful idea in the study of electricity.

A: Resistors in Series

1. **Explain.** In the previous lesson, we thought about the resistance of two bulbs connected in series. Now suppose we connect three different resistors in series. What do you think the total or *equivalent resistance* of this network of three resistors will be equal to? Use the traffic analogy from the previous lesson to explain.



2. **Build.** Use the simulator to construct the circuit shown to the right. Label the three resistors with their values (right click to change resistances).
3. **Observe.** Measure the voltage across the battery and current through the battery. Record these measurements below the symbol for the battery.
4. **Calculate.** Since we know the current and voltage for the battery, we can use Ohm's Law to calculate the total resistance of the network the battery is connected to. Show your work.

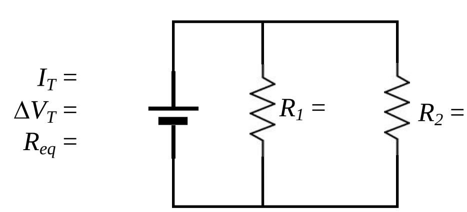
Note that the total resistance means the total resistance of the network the battery is connected to and **not** the resistance of the battery itself. We will use the *ideal battery approximation* that batteries have zero resistance. In reality, they have a small internal resistance.

5. **Find a Pattern.** On the basis of your experimental results, create an equation that describes the *equivalent resistance* when a number *n* of different resistors are connected in series. Use the notation R_{eq} and R_1, R_2, ... R_n in your equation.

Rule for the Equivalent Resistance of Elements Connected in Series

B: Resistors in Parallel

1. **Explain.** Imagine we connect two identical resistors in parallel. Would the total resistance of this network be greater than, less than or the same as a single resistor? Explain using the checkout counter analogy.



2. **Build and Measure.** Construct the circuit shown to the right. Label the two resistors with their values. Measure the voltage across the battery and current through the battery. Record these measurements beside the symbol for the battery.
3. **Calculate.** Since we know the current and voltage for the battery, we can use Ohm's Law to calculate the total resistance the battery experiences due to the two resistors. Show your work.

4. **Describe.** How does the equivalent resistance of the network of two resistors connected in parallel compare with a single resistor?

Rule for the Equivalent Resistance of Elements Connected in Parallel

The equivalent resistance of a group of resistors connected in parallel is given by the expression: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

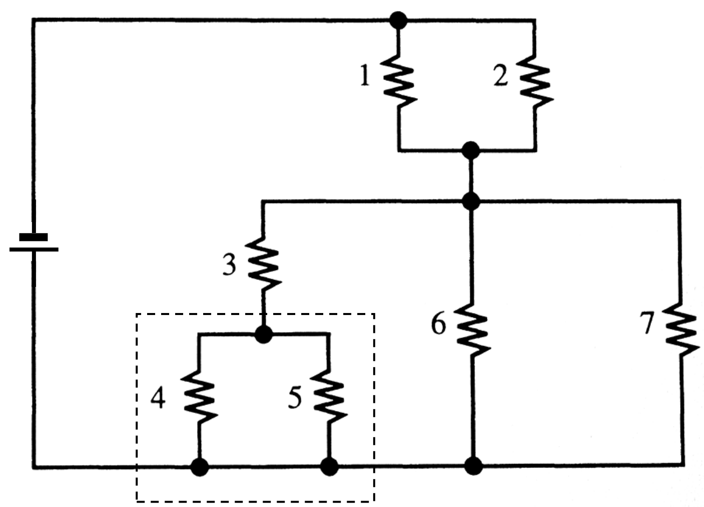
When connecting resistors in parallel, *the equivalent resistance decreases*.

Problem Solving Hint: When you calculate the equivalent resistance of a network of elements in parallel, if the numbers are easy to work with, complete the calculation using fractions. If the numbers are not, find a decimal result for $1/R_{eq}$ and then find R_{eq}.

C: Circuit Decomposition

We can analyze complicated circuits by identifying smaller parts or networks whose parts are connected strictly in series or parallel and *decompose* the complex circuit into simpler parts. A complex circuit is shown below. It contains one 9.0 V battery and seven identical 100 Ω resistors. To find the equivalent resistance of all seven resistors we must proceed in steps:

- Identify a network of two or more resistors that are connected strictly in series or parallel.
- Find the equivalent resistance of the network.
- Replace the network by a single resistor of that value.
- Repeat the process until there is only one resistor left.



1. **Observe.** Examine the circuit. Are there any groups of resistors connected:
   (a) in series?

   (b) in parallel?

2. **Calculate.** Draw a box around the network of resistors 4 and 5. Determine the equivalent resistance of this network. Use the symbol R_{45} for their equivalent resistance. Show your work here (use the fraction technique).

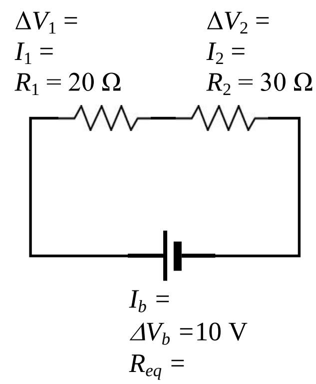
3. **Represent.** Write R_{45} = 50 Ω next to the box. You should now think of that box as a single resistor with a resistance of 50 Ω.

4. **Calculate.** Continue this process. Your boxes will become larger and larger (draw them neatly so things don't get too messy!) Show all your calculation below. Be sure to label the equivalent resistance of each box.

5. **Calculate.** What is the equivalent resistance of the entire network the battery is connected to? Calculate the current flowing through the battery. Show your work.

SPH3U: Equivalent Resistance Homework   Name:

1. **Solve.** A simple series circuit is shown to the right. When you do your work analysing a circuit, always record the final results next to the element in the circuit diagram. Also show your work carefully with the proper symbols.



   (a) Find the equivalent resistance of the circuit. Record the result beside the battery.

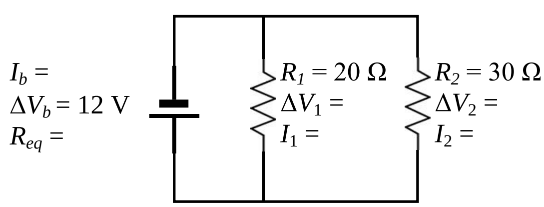
   (b) If we know two quantities from the equation $\Delta V = IR$ for any element in a circuit, we can find the third. Do this!

   (c) Find the current flowing through each element of the circuit.

   (d) If we know two quantities from the equation $\Delta V = IR$, we can find the third. Do this!

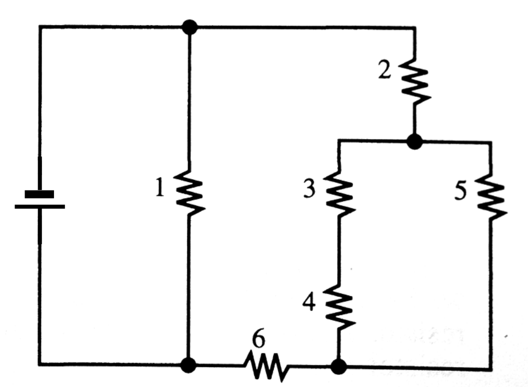
   (e) Check your analysis: do the voltage results obey our voltage law? Explain.

2. **Solve.** A simple parallel circuit is shown to the right.
   (a) Find the current and voltage for each element in this circuit. Show your work carefully.



   (b) Check your analysis: do the currents obey our current law? Explain.

3. **Solve.** Each resistor in this circuit has a resistance of 30 Ω.
   (a) Find the equivalent resistance of the circuit to the right. Show your work.

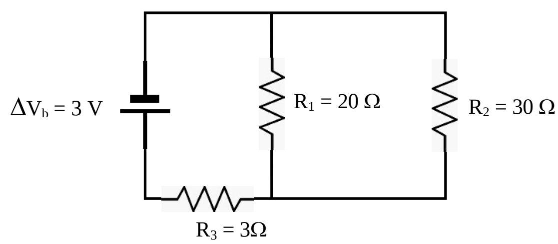


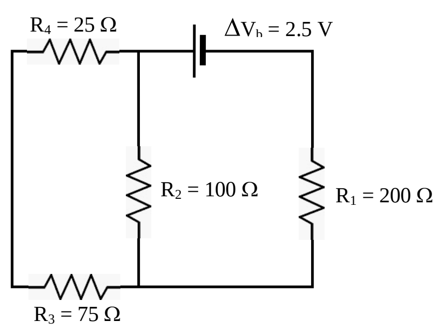
   (b) The battery in this circuit has a voltage rise of 10 V. What is the current flowing through the battery?

SPH3U: Circuit Analysis Homework Name:

Time to practice your new skills! Remember our strategies in our circuit work:

- Look at what information you know about your circuit and use your toolbox to help decide what you can find next.
- Write out a complete equation using symbols.
- Show your calculations and substitutions carefully
- Use the simulator (PhET circuits) to check your answers!





SPH3U: Circuit Analysis

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

We have developed a complete set of tools to help us analyze simple electric circuits. In this investigation, you will learn how to apply all of them to completely analyze an electric circuit.

A: Your Toolbox – Rules for Electric Circuits

Summarize the tools that you will use to analyze a circuit. For each situation listed below, describe the rule or "tool" you would use to analyze that situation and include a simple equation as an example.

1. The equivalent resistance of elements connected in series:

2. The equivalent resistance of elements connected in parallel:

3. Current flowing in and out of a junction:

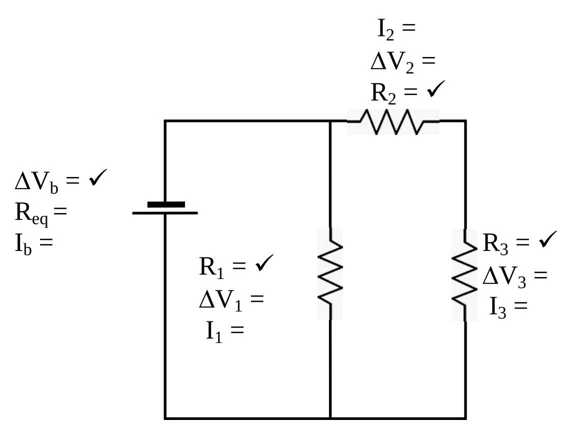
4. Voltage rise or drops along a circuit loop :

5. Relationship between current, voltage and resistance for a single element:

B: Circuit Analysis – A Walk Through

Let's walk through the thinking process for one circuit together. The circuit is shown below. We start off knowing the voltage of our source and the resistance of each resistor, but we haven't given you the exact values. As you go through the analysis, write an equation for each unknown quantity and check off that quantity in the circuit diagram.

1. **Reason.** Examine the information you are given. Since we know the resistances, we can find the equivalent resistance of the entire circuit ($R_{eq} = R_{123}$). Write down the equations you would use. You don't need to do any math work.



Whenever you know two quantities for any circuit element, you can find the third using Ohm's Law. Remember this trick!

2. **Reason.** Use Ohm's Law to find an important current value. Write down the equation here.

3. **Reason.** We now have current information for the circuit. Even if we knew this value, we wouldn't be able to use it to find other current values. Why?

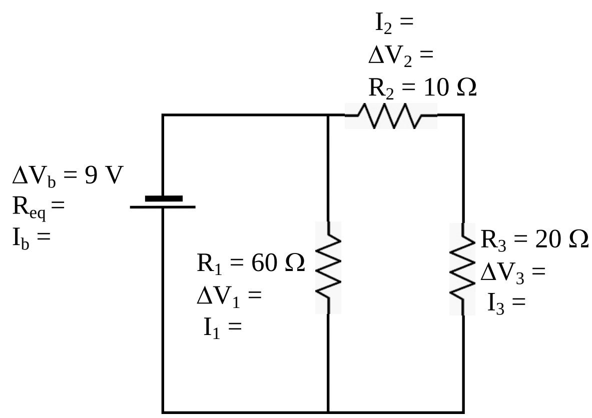
4. **Calculate.** Since we can't use current ideas yet, turn to voltage ideas. Use the voltage law to determine a missing voltage value. Then use Ohm's law. Write down the equations here.

5. **Reason.** Use the current law to find the missing current values. You will need to write down <u>two</u> equations to do this.

6. **Reason.** Find any other missing values. Write down two equations. Now everything should be checked off on your circuit diagram.

C: Circuit Analysis

Now it's your turn! There are two good habits we would like to cultivate: (1) record the results of your calculations alongside the circuit element (no checkmarks required), and (2) carefully show your logic by writing the equations using symbols first. Completely analyze the circuit by finding the current, voltage and resistance for every element. Build the circuit in the simulator to check your answers.



SPH3U: Magnetic Interactions

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

A: Looking for Magnetic Interactions

Your group needs one bag of mystery materials, one watch glass, and two bar magnets.

1. **Reflect.** If we ask a young child, "what kinds of materials are magnetic," what do you think the typical child would say?

2. **Play.** Explore the interactions between various combinations of materials. Balance one bar magnet on the watch glass. Nobody is allowed to "just watch", everybody needs to participate! Spend about five minutes on this.

Induced means "to bring about" or "to give rise to". In this unit we use this word to describe something that is not normally there, but can be produced due to the influence of something else. In today's investigation, some objects don't normally have strong magnetic effects but *can* have strong magnetic effects when they are near other objects.

3. **Find a Pattern.** Explore how your materials interact with the **two** ends (the red and grey ends) of your bar magnet. Use your observations to sort your materials into three categories based on their interactions: (A) permanent magnets, (B) induced magnets, and (C) non-magnetic. Create a chart showing your results.

4. **Predict.** Let's use our understanding to make a prediction about a compass needle. Three students develop three different hypotheses: the compass needle is (A) a permanent magnet, (B) an induced magnet, and (C) is non-magnetic. Based on each hypothesis, how would the compass needle interact with the two ends of your bar magnet?
   (A) Permanent Magnet:

   (B) Induced Magnet:

   (C) Non-magnetic:

5. **Test.** Get a compass. Use your bar magnet to test the three predictions. Which hypothesis is supported, which are refuted?

6. **Apply.** You have just determined what type of material a compass needle is. Predict what will happen if we bring the end of a paperclip into contact with the compass needle itself. Your teacher has a compass needle that is removed from its case.

7. **Test.** Check your prediction using your teacher's compass needle. Record your observations. Do the observations verify your prediction?

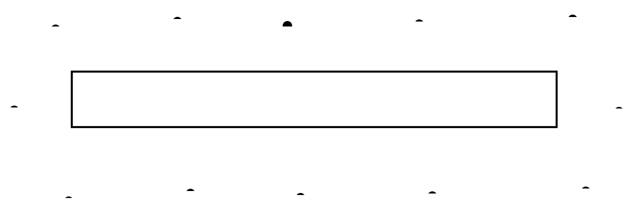
B: Picturing Magnetic Interactions – The Magnetic Field

A compass needle is a tiny bar magnet that helps us detect magnetic interactions. The "N" or coloured end of a compass needle is the north pole of a bar magnet. As you likely know, similar magnetic poles repel and opposite poles attract. We will use a compass to help decide if magnetic interactions are present and find a direction associated with those interactions.

1. **Observe.** Move all your objects far away from your compass. Is there any evidence for the existence of a magnetic interaction? Explain.

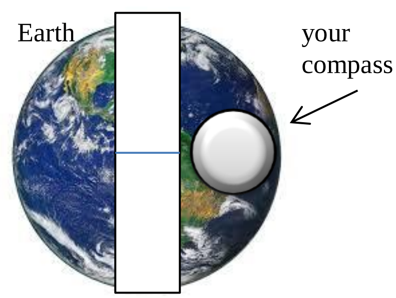
Every time you use a compass, you need to check that it is properly magnetized! Place it on a level surface, far away from any other magnetic objects. Determine which direction is geographic north (where Santa lives). Tap the compass to make sure it is not stuck. The "N" or coloured end of the compass needle should point towards geographic north.

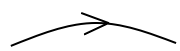
2. **Observe.** Place the compass at each point in the region around your bar magnet as shown to the right. Draw an arrow showing the direction of the compass needle at that position in space.

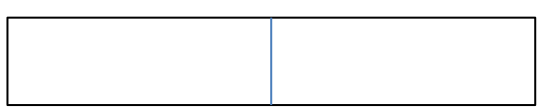


3. We can model Earth's magnetic interactions by representing Earth as a giant bar magnet!
   (a) **Represent.** Use an arrow to show the direction the north end of a compass needle will point when it is placed at the position shown in the diagram.

   (b) **Explain** the orientation (the poles) of Earth's "bar magnet". Labels the poles in the diagram – this should be surprising!



4. **Observe**. Use the PhET applet "Magnets and Electromagnets" to see what it would look like if many, many compass needles were placed in the region of space around the bar magnet. Be sure to select the option: "see inside the magnet". Imagine we draw lines through space that follow the paths pointed out by the compass needles.
   (a) Draw these lines in the space below.
   (b) Add arrowheads to the lines to show the compass needle directions, like this: 



You have just constructed a picture of the *magnetic field* in the region of space around (and inside!) the bar magnet. On the **outside** of a permanent magnet, field lines point from north to south. Notice that magnetic field lines actually continue inside the magnetic object and form **closed loops**.

This picture is a powerful tool that allows us to *see* the strength and direction of the magnetic effects. We interpret this picture in two ways: (1) The arrows show the direction a compass needle would point at that position in space, and (2) the *density* of lines (number of lines in a unit of area) shows the strength of the magnetic interactions. Like our work with bar charts, the total number of lines is not really important, what is important is how the density of field lines in different regions compares.

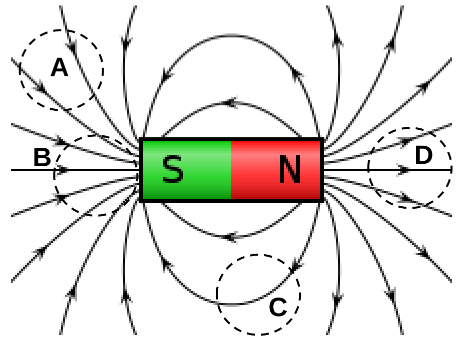
SPH3U: Magnetic Interaction Homework Name:

1. **Reflect.** How can we use a compass to investigate a magnet and its magnetic field? If we "follow" a compass, which end of a bar magnet will it lead us to?

2. **Interpret.** A bar magnet has a magnetic field shown in the diagram to the right (the field lines inside it are hidden). Four regions of space have been circled.
   (a) A compass is placed in each circle. In the space below, draw the direction the compass needle would point.

   A: B: C: D:

   (b) Rank the strength of the magnetic field in each region from strongest to weakest. Explain your reasoning.



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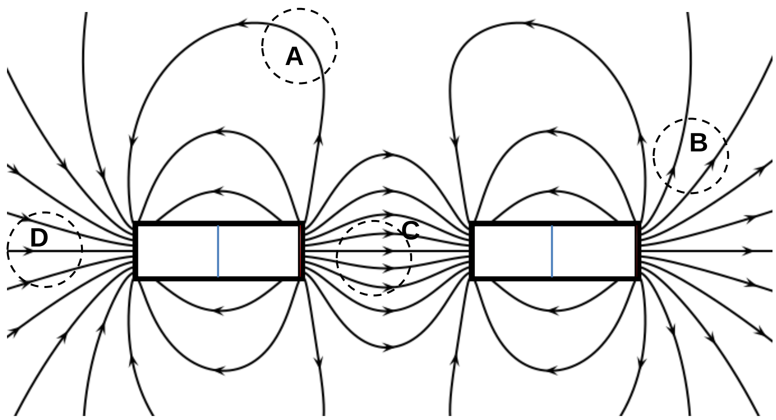
3. **Interpret.** Two bar magnets have a magnetic field shown in the diagram to the right. Four regions of space have been circled.
   (a) A compass is placed in each circle. In the space below, draw the direction the compass needle would point.

   A: B:

   C: D:

   (b) Rank the strength of the magnetic field in each region from strongest to weakest.



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   (c) Label the poles of the two magnets (compare with the illustration above).

   (d) Describe to an elementary school student what the two bar magnets are "doing to each other".

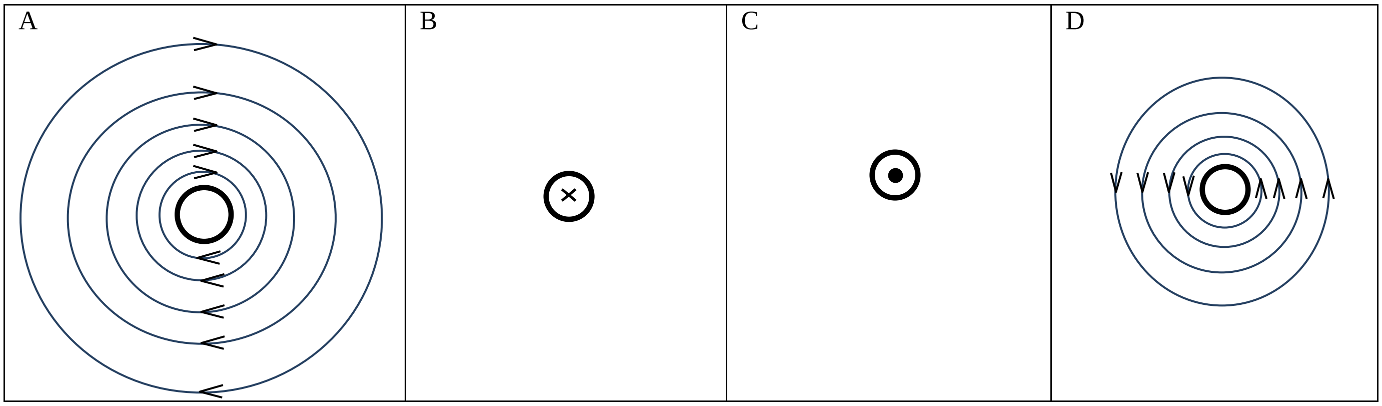
   (e) Explain how you decided what the two bar magnets are "doing to each other".

4. **Investigate.** Chances are, you have magnets attached to your refrigerator at home. A **flat, flexible** fridge magnet is a permanent magnet, but behaves strangely! Investigate why. (If you don't have any handy, do some internet research.) Try attaching two together and sliding them across one another.

SPH3U: Electromagnetism Homework   Name:

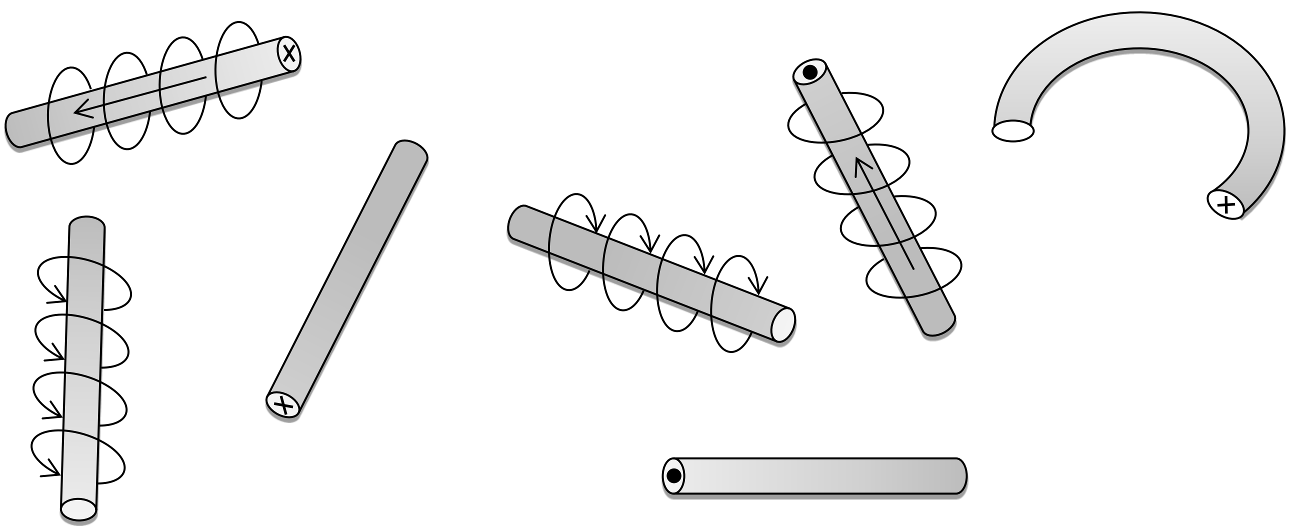
1. **Reflect.** Explain as if you were talking to an interested friend the important ideas from today's lesson.

2. **Represent.** Each diagram below needs to be completed with the magnetic field or the current. Use the curly left hand rule to complete each diagram.



3. **Reason.** Use a coin to circle three regions in space in magnetic field diagram A from question #2. Rank the three regions you have selected from weakest to strongest magnetic field. Explain your reasoning.

4. **Represent.** Drawing magnetic fields in three dimensions takes a bit of practice. Let's give it a try! Complete the missing parts of each diagram: field arrowheads, field lines, current arrow, or current in/out vector. Examples of each are shown below.



5. **Reflect.** What is one question that would be helpful to ask your teacher to check your understanding of magnetism, based on the work we have done so far?

SPH3U: Electromagnetism

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

In 1820, the Danish scientist Hans Christian Øersted happened to leave a compass nearby a wire during an electricity experiment and made a shocking discovery!

A: Shocking Discovery!

You need a 3-V battery pack, a wire, and a compass.

Warning! In this experiment you will be short-circuiting the battery by connecting the two ends of one wire to the positive and negative battery terminals. **Do not leave the wire connected to the battery** because the battery will overheat and be ruined. Clip one end of the wire to one terminal and simply touch the other end of the wire to the other terminal.

1. **Play.** Hold the middle of the wire as near as possible to the compass needle. Connect the wire to the battery (follow the advice above) to allow a current flow. Try out lots of different combinations: different connections, different locations along the wire, different time intervals. Be creative! Nobody is allowed to "just watch", everybody must try! Take 5 minutes for this.

2. **Observe.** Create a chart that lists observations you think are important (your discoveries!). Your chart entries should describe how you set-up the equipment and the resulting effect on the compass.

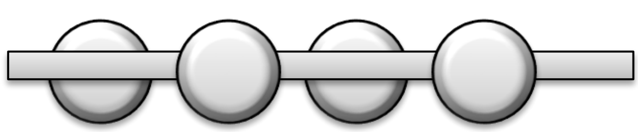
3. **Describe.** In a simple way, describe what you think Oersted's discovery was.

B: Exploring the Magnetic Field of a Wire with Current

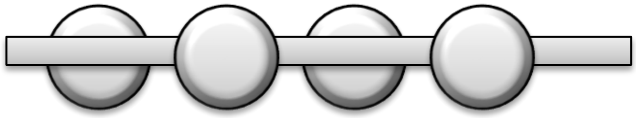
Warning! The next experiment uses a high-current power supply. **Do not** touch the wires when the power is on. **Do not** connect the wires to anything other than the two indicated terminals of the power supply. **Do not** increase the power beyond the indicated level. **Check** that the power is turned off at the start and end of your experiment.

1. **Safety Check.** (*Recorder: Make sure your group records their answers to this question*.) Are you and your group members able to follow the safety instructions described above? Do you or your group members have any questions about the safety instructions? Be sure to ask your teacher **before** proceeding.

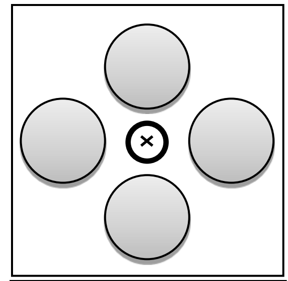
2. **Observe.** If there is a line-up for this equipment, you can go to question B#3. Your teacher has a wire, power supply, and compasses set up at the front of the class. You may use this to make your next set of observations.
   (a) Turn on the power and observe the direction of the compass needles. **Turn off the power**. Make sure your diagram below lines up with the equipment. Use an arrow to draw the direction of the compass needles **and** the direction of the electron current in the wire.



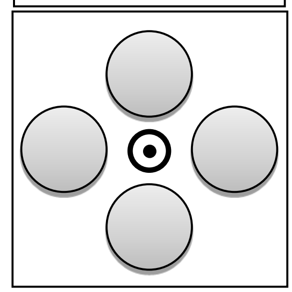
(b) Make a simple change to the wires of circuit that changes the reading of the compass needles. Observe, then turn off the power. Draw the direction of the compass needles **and** the direction of the electron current in the wire.



In our study of magnetism, we will need to illustrate vectors that are pointing in three different dimensions. To do this, we will illustrate vectors that are pointing out of our page using the symbol "•". A vector that is pointing into our page will be represented with "×".



3. **Observe.** The diagram to the right shows four compasses set up around a wire that is pointing straight up. You are looking at this from above. The electron current is travelling down the wire, into the page. This is shown by the "×" in the diagram.
   (a) Check that the wires are connected to the power supply such that the electron current will travel **down** through the wire.
   (b) Turn on the power supply and observe. Turn off the power supply and record your observations in the same diagram.



4. **Predict.** You will change the direction of the current in the wire so it travels up, out of your page. Predict the direction the compass needles will point. Draw these lightly in the second diagram.

5. **Observe.** Check that the wires are connected properly to the power supply. Turn on the power supply and observe. Turn off the power supply and record your observations.

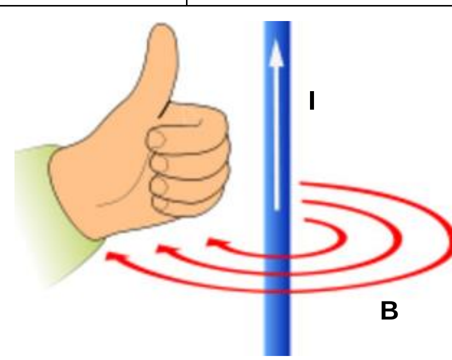
C: The Magnetic Field of a Straight Wire with Current

1. **Play.** Use the magnetic field app found at: http://www.falstad.com/vector3dm/. This app should run on most phones. Select "Display: Field Vectors". This gives you a 3-D view of the field vectors (the "compass needles"). If you find this hard to see, change "No slicing" to "Show Z Slice". Also, select "Display: Field Lines". Try out different combinations of these settings. **Note: the simulator uses a different model for electric current. The yellow current arrow is opposite to what we use.**

2. **Observe.** Find the settings that allow you to best see the shape of the magnetic field lines around the wire. Illustrate these field lines and add arrowheads to show the directions of the lines (the direction a compass needle at that position would point).

Current into page	Current out of page
⊗	⊙

The **left-hand rule for straight conductors** describes the connection between magnetic field lines and electron current for a straight wire. Point your left-hand thumb in the direction of the electron current and your fingers will curl in the direction of the magnetic field created by the current in the wire.



By Jfmelero - Own work, GFDL, https://commons.wikimedia.org/w/index.php?curid=3634402

3. **Explain.** Does the left hand rule for conductors agree with your observations from questions B#3 and B#5? Explain.

SPH3U: The Domain Theory of Magnetism

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

In our first lesson, we saw how certain materials could become strongly magnetic in the presence of an external magnetic field (the induced magnets). Time to figure out how this happens!

A: Induced Magnetism

You need a nail, a bar magnet, and a bunch of paper clips.

1. **Plan.** Devise a simple test using your materials that will help you observe the strength of the nail's magnetic field. Explain how your test works.

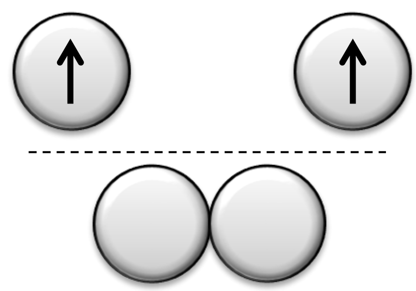
2. **Observe.** Use the bar magnet to induce a magnetic field in the nail. Test the strength of the nail's new magnetic field.

3. **Observe.** Remove the bar magnet. Test the strength of the nail's magnetic field. Is there any evidence for a left-over magnetic field? (Check carefully!)

B: The Domain Theory of Magnetism

We cannot easily see inside the nail and observe what is happening in the situations you explored above. However, careful investigations can help us create a model that describes induced magnetism.

1. **Predict.** Remind yourself: what kind of magnetic object is a compass needle? If you move the two compasses as close as possible together, predict how the compass needles might interact with one another and point (there are two possibilities). Explain your prediction.

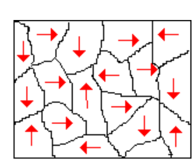


2. **Test.** Your teacher has a pair of compasses set up at the front of the class. Move the two compass needles close together and observe. Record your observations in the lower diagram.

People have long noticed that even the tiniest pieces of iron interact magnetically. A careful exploration of the electron structure of a single iron atom reveals that each atom of iron has its own magnetic field and behaves as a tiny bar magnet. You will learn more about this in that other physics course (chemistry). The iron atoms in a solid have their positions fixed (that's why it is solid), but the electrons can sometimes shift around the atom, like a compass needle.

3. **Observe.** Your teacher has a set of compasses arranged in a grid. Can the compasses themselves move around? What do you think each compass needle in this model represents?

The *domain theory of magnetism* explains that iron atoms often collect into *domains*, regions where the magnetic fields of the atoms point in a similar direction. If a domain is large, a large overall magnetic field is produced. If domains are small, or are not present, the total magnetic field is small or close to zero. We can represent domains using a *domain diagram* where arrows represent direction of the magnetic field within the larger material. For convenience, we only draw one arrow per domain.

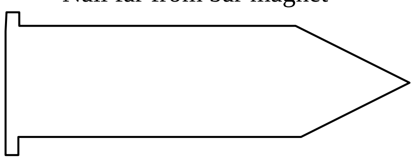


4. **Observe and Represent.** Gently move your hand through the compass needles to start them spinning. It takes a while for them to settle down: much, much longer than for iron atoms. Read the box below. Once they have all stopped, draw a domain diagram. How many domains are there?

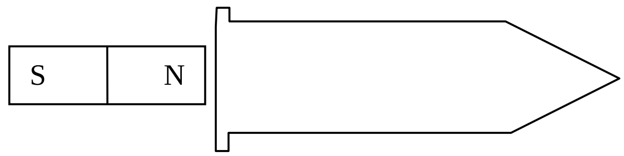
C: Master of Your Domain

1. **Represent.** Draw a domain diagram for your nail during your observations in part A when it was near the bar magnet and another diagram for the nail just after the bar magnet was removed.

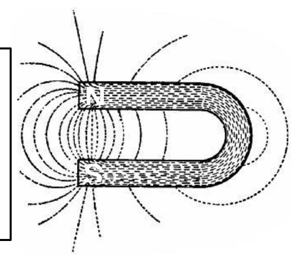
Nail far from bar magnet



Nail very close to bar magnet



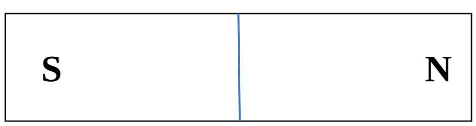
2. **Predict.** A horse shoe magnet has a magnetic field similar to the illustration shown to the right. Your teacher has a very strong horseshoe magnet. If we hold the magnet near the grid of compasses, draw what you think the domain diagram would look like.



3. **Observe.** (*as a class*) Hold the horseshoe magnet near the grid of compass needles. Do the compasses verify your domain diagram? Explain.

4. We mentioned that even the smallest pieces of iron behave like tiny bar magnets. Iron filings are tiny, ground-up bits of iron. In your next experiment, you will take a bar magnet, cover it with a piece of acetate (transparent plastic), and add iron filings on top of the plastic. The filings are small enough that they will move across the acetate due to the bar magnet's magnetic field. We will picture each filing as a single, tiny compass arrow.
   (a) **Explain.** Where do you think the filings are likely to go? How will they interact with one another?

   (b) **Represent.** You will soon add lots of filings to one end of the bar magnet (on top of the acetate). Draw lots of little arrows representing the filings. How will they connect with the bar magnet, how will they connect with each other? What do you think the end of the bar magnet will look like?



5. **Observe.** Get a piece of acetate and the iron filing shaker. Make sure the acetate covers the bar magnet so the filings never actually touch the magnet – this will make your clean-up **much** easier. Shake filings onto your acetate all around the bar magnet. Gently tap the plastic to jiggle the filings a bit. Complete the diagram above by adding in more arrows representing the chains of iron filings that formed.

6. **Clean Up.** To clean up or "reset" your iron filing picture, lift the acetate **straight upwards**, off the bar magnet. Don't let the filings slide on to the magnet! Open the lid of the filing shaker and pour them back in. Sweep any filings off the table on to the acetate and then into the shaker. Any filings attached to the bar magnet need to be wiped off using paper towel.

7. **Play.** Try combinations of two bar magnets under the acetate (keep some space between the poles). Use the acetate and filings to explore the interacting magnetic fields. Clean up when you are done.

SPH3U: The Strong Field Mystery

Recorder: ______________________	
Manager: ______________________	
Speaker: ______________________	
0 1 2 3 4 5	

Today we create a mystery: how do we create a strong magnetic field without a permanent magnet? And solve the mystery: what causes such a large field?

A: The Paperclip Challenge

You need a wire with alligator clips, a nail, a small bunch of paper clips, and a 3-V battery pack.

Warning! In these experiments you will be short-circuiting the battery. **Only connect to the battery long enough to make your observations, then disconnect it!**

1. **Observe.** How strong is the magnetic field around your wire when it is connected to the battery? Describe your observations and conclusions.

2. **Play.** Find a way to use the nail and wire together (no bar magnets!) to create a magnetic field strong enough to pick up a number of paper clips. On a whiteboard, record the greatest number of paperclips you could pick up magnetically at one time. Keep improving your result! Make sure each group member has a turn!

B: Creating a Testing Experiment

Question: What is responsible for creating such a strong magnetic field?

We have observed a very mysterious result: a strong magnetic field without a permanent magnet! We want to solve the mystery by answering the question above. To do this, scientists (that's you!) go through a process of: (a) generating multiple *hypotheses*, (b) designing *testing experiments*, (c) making predictions, (d) performing testing experiments, and (e) evaluating the results.

A possible explanation for why something happens is called a *hypothesis.* A hypothesis needs to be *tested* to decide how reliable it is. A *testable* hypothesis is one that we can imagine designing an experiment for that would be able to test whether or not it was reliable.

3. **Speculate.** You probably created a strong magnetic field by wrapping your wire around the nail. As a result, the field is now much stronger than that of the straight wire in question A#1. Think of all sorts of *crazy ideas* that might explain why the field is stronger now. Don't worry about whether the ideas are right or wrong – the goal is to come up with more than one possible idea! Write your ideas here and **briefly** on your whiteboard.

4. **Explain.** Now we will generate two hypotheses. A good, testable hypothesis will focus on **one** idea at a time to try to identify which idea is an important one. Remember, each hypothesis is an attempt to explain how some change you made resulted in a stronger magnetic field.

   Hypothesis A:

   Hypothesis B:

The purpose of a *testing experiment* is to produce evidence that will support or refute the prediction of a hypothesis. This is usually done by carefully changing just one characteristic of the situation and observing the outcome. Multiple testing experiments are usually needed before we can be confident that we have a reliable scientific explanation and have carefully eliminated all other possible hypotheses.

5. **Plan.** Devise two simple testing experiments that will help to test each hypothesis. Think about simple changes you can make that could affect the strength of the magnetic field. Record a description of each testing experiment in the chart below. Don't do any experiments yet! If you are stuck, ask your teacher!

	Experiment 1	Experiment 2
Description		
Prediction A		
Prediction B		
Observations		

A prediction is a description of the outcome of an experiment according to the ideas of a particular hypothesis. To make a prediction we assume that one hypothesis is correct while the others are wrong. Then we ask ourselves, "if this hypothesis is correct, what would the outcome of the experiment be? What would we *measure* or *observe*?"

6. **Predict.** With two hypotheses and two experiments, you need to create four predictions in total.
   (a) Assume hypothesis A is the correct explanation and B is wrong. Describe the outcome of each experiment according to hypothesis A. Record these predictions in the chart above. Remember: we cannot "see" a magnetic field, what will we *observe* happen?
   (b) Repeat this process, now assuming that hypothesis B is the correct one. If you are not sure, please ask your teacher!

** *Call your teacher over to check your predictions* **

7. **Test and Evaluate.** Conduct your experiments and record your observations in the chart above. Which hypotheses are supported and which are refuted by your evidence?

8. **Explain.** Draw a diagram showing your electromagnet, including the interior of the nail, the wire and the battery. Based on your results, provide a complete explanation for the increased strength of the magnetic field. Explain the role of each part in the diagram.

9. **Speculate.** If you wanted to make a super strong magnetic field, what would you do? Think of lots of possible ideas!

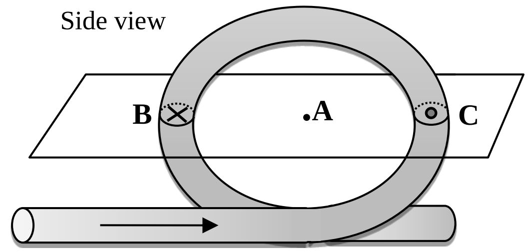
Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

SPH3U: The Magnetic Field of Loops and Coils

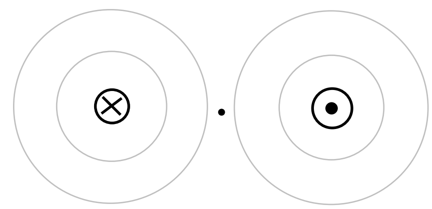
In our previous investigation, creating loops of wire helped produce a stronger magnetic field. Let's explore what is happening here, starting with a single loop of wire.

A: The Loop

1. **Represent.** (a) Draw arrows in the wire showing the direction of the electron current. (b) Use the curly left-hand rule and a **different colour** to draw the magnetic field lines around the loop in the upper diagram.



2. **Represent.** We want to explore the magnetic field near the centre of the loop (point A). To help us do this, imagine the loop of wire passes through a piece of paper. Let's focus on the current at the two points B and C where the current goes in and out of the page. In the lower diagram, draw the magnetic field lines around the wire at point B and C.



3. **Interpret.** Imagine we place a compass at point A. In what direction will it point? (Hint: imagine expanding the size of your field circles until they reach point A.)

4. **Reason.** You have drawn two sets of field lines near point A.
   (a) What will be the combined effect of these two field lines on the compass needle? Explain.

   (b) In reality, every part of the wire (not just points B and C) will generate magnetic field lines like the pair you have drawn. What will the combined effect of these field lines have on the magnetic field strength at the centre of the loop?

5. **Review.** In the next test, you will be using a high-current power supply. Summarize in the space below our safety rules from the previous electromagnetism investigation.

6. **Test.** Your teacher has a wire loop set up at the front of the class. Make sure the wires are connected such that the current flows in the same direction as in your diagram. Turn on the power supply, observe, turn off the power supply, and record your observations.

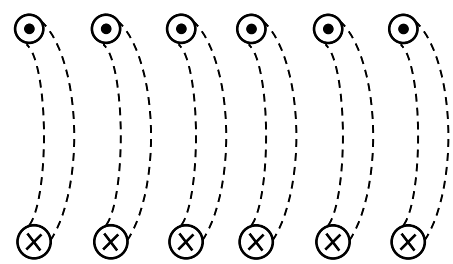
7. **Evaluate.** Do your observations confirm your prediction?

8. **Represent.** The magnetic field around a loop of wire is three-dimensional. To visualize this, use the applet: http://www.falstad.com/vector3dm/. This app should run on most phones. Select "Field selection: current loop" and "Display: Field Lines". This gives you a 3-D view of the field. Next, change "No slicing" to "Show Y Slice". This should look similar to your diagram above, but notice how the field lines combine! Draw a simplified sketch of this magnetic field.

C: The Solenoid

A solenoid is a long coil of wire – many loops put together! Scientists and engineers use solenoids because of the special magnetic field that is created in the space *inside* the coil. A solenoid is set up at the front of class. Please follow your safety procedures for working with a high-current power supply.

Top view (looking down on to the plastic plate)

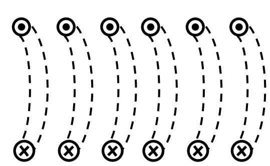


1. **Set Up.** We are interested in the total magnetic field created by the loops of wire. Make sure the wires are connected to the power supply to produce the electron current shown in the diagram to the right.

2. **Observe.** Draw the direction of the compass needles in the diagram.

3. **Predict.** What would be different if you reverse the direction of the electron current?

4. **Test.** Try this out. Describe your observations.



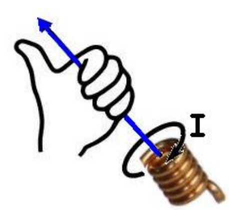
5. **Represent.** To visualize the full magnetic field, use the applet: http://www.falstad.com/vector3dm/. Select "Field selection: solenoid" and "Display: Field Lines". This gives you a 3-D view of the field. Next, change "No slicing" to "Show Y Slice". You can rotate the image to match our diagram. Use the applet to draw the magnetic field lines in the second diagram.

6. **Represent.** Use your compass needle observations to add arrowheads to the field lines you have just drawn.

7. **Reflect.** This magnetic field is similar to another that we explored earlier. What object produced this field? Where is the "north pole" of the solenoid field?

There is no physical object that corresponds to our idea of a north or south magnetic pole. The north pole of a magnet is simply a region in space where the magnetic field lines spread out from (diverge). The south pole is a region in space where the field lines come together (converge).

The **left-hand rule for coils** helps us relate the direction of the field lines with the direction of the current for any coil (even for a single loop!). The fingers of your left hand wrap in the direction of the electron current and your thumb points to the north pole of the solenoid's field. Note that this is different from our previous left-hand rule!

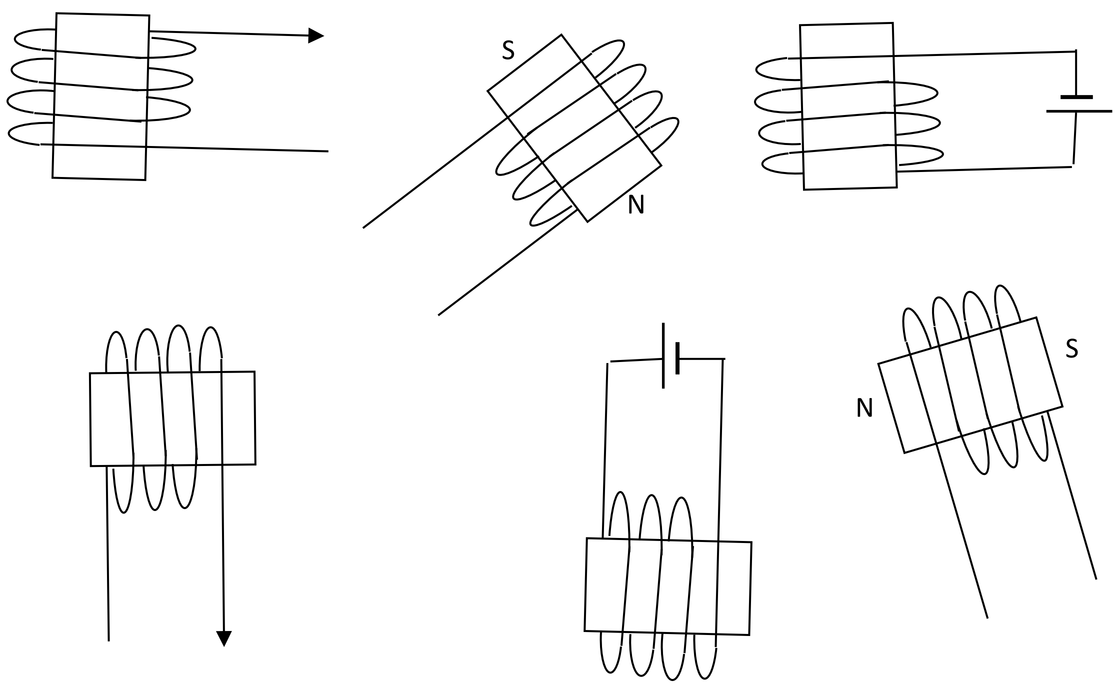


8. **Evaluate.** Does the left-hand rule for coils agree with your loop and solenoid observations? Explain.

SPH3U: Loops and Coils Homework   Name:

In our investigation, we learned how to find the direction of the magnetic field lines using the left-hand rule for coils. We also noticed that the magnetic field of the coil has a similar shape to that of a bar magnet. As a result, we can think of the coil as having a north and south magnetic pole. For the left-hand rule for coils, your thumb points in the direction of the magnetic field and in the direction of the “north pole”.

1. **Represent.** For each coil shown below, complete the missing parts: the direction of the electron current flow in the wire and the polarity of the magnetic fields.



2. **Investigate.** A solenoid produces a large, uniform magnetic field inside the coil. “Uniform” means that the strength and direction of the field is the same. This type of field has many important applications. One of these is magnetic resonance imaging (MRI). Do some internet research and explain the key ideas behind this amazing technology. Describe:

   (a) the magnet and its field

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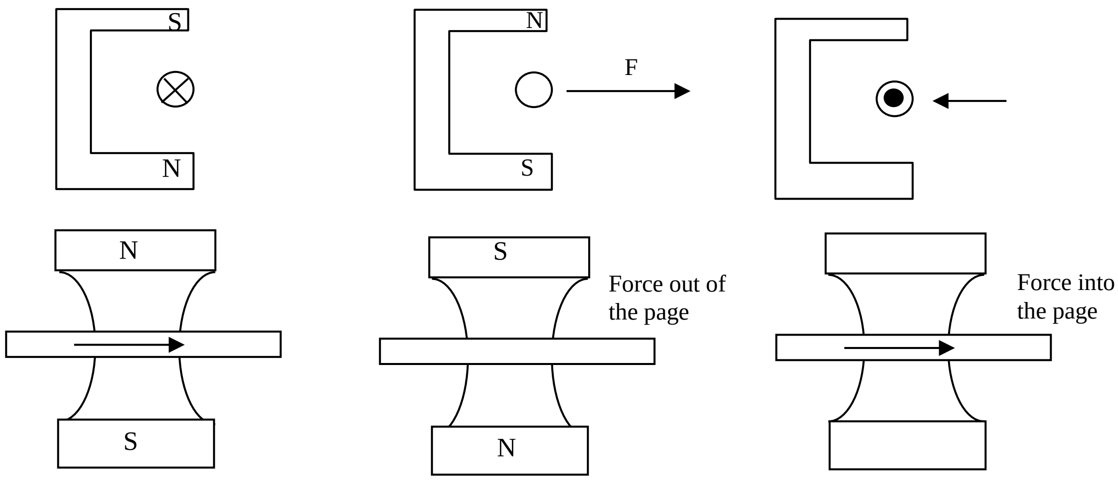
By Kieran Maher at English Wikibooks - Adapted with permission by Kieran Maher using Graphic Converter from Applied Imaging Technology by Heggie, Liddell & Maher (2000)., Public Domain, https://commons.wikimedia.org/w/index.php?curid=12766438

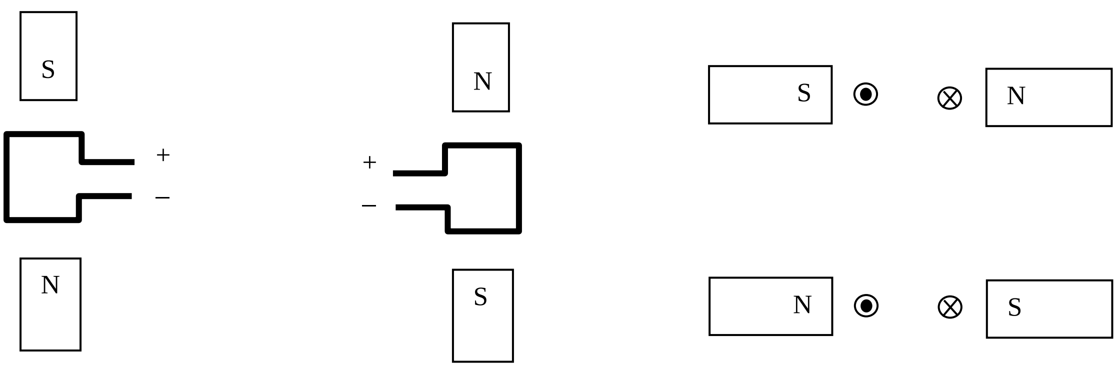
   (b) how the radiation interacts with the person’s tissue.

SPH3U: Motor Principle Homework   Name:

1. Each diagram below shows a different horseshoe magnet and a wire with current that runs through the magnetic field of the magnet. Complete the missing parts of the diagrams: direction of the electron current, magnet polarity or force. Use the symbol ⊗ for a vector pointing in to the page, and use the symbol ⊙ for a vector pointing out of the page.



2. The diagrams to the right show four different motors: two from a top view and two from a side view. Each motor consists of a loop of wire carrying a current and a pair of field magnets. Show the direction of the force on each half of the loop and indicate the direction in which the loop will turn.

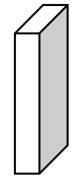


SPH3U: The Motor Principle

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

A: Magnetic Forces on Moving Charges

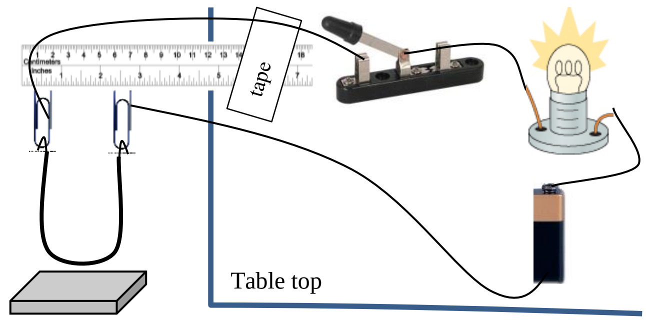
You need a ceramic magnet, a compass, a battery pack, the swinging wire ruler, a bulb, a few wires, and a switch.



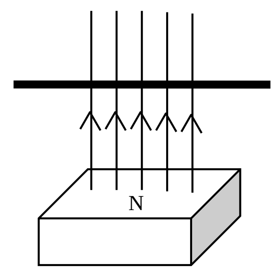
1. **Observe.** Stand the ceramic magnet up on end. Move the compass around the magnet and determine the location of the north and south poles. (If there are already markings, confirm that another group didn't get it wrong!) Mark the surface of the magnet with an "N". Show this in the drawing to the right. Draw the magnetic field lines that travel in and out of these surfaces.

Attach the ruler to your table so the "U" wire can swing freely. Connect the rest of the circuit. Hold the magnet underneath the "U" with north facing up.

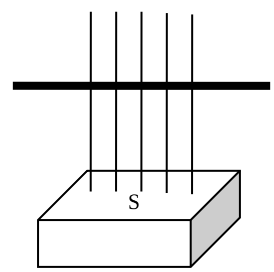
2. **Observe.** Connect the two leads to the battery and close the switch. Observe, then open **the switch**. Carefully describe what you observe.



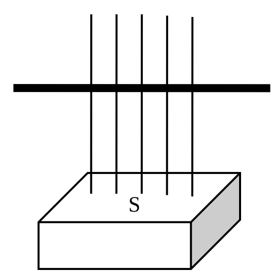
3. **Represent.** Since you have the north pole of the magnet facing up, the magnetic field lines just above the surface of the magnet also point directly upwards. In the diagram below to the right, the magnet, the field lines and the wire are shown.
   (a) Draw an arrow showing the direction of the electron current flow.
   (b) Draw a vector showing the direction of the magnetic force acting on the wire. Use the symbols for into and out of the page. Label the force vector $\vec{F}_m$.



4. **Represent.** Turn over the magnet such that the south pole is facing upwards. Close the switch. Observe. Open the switch.
   (a) Draw arrows showing the direction of the magnetic field, the direction of the electron current flow, and the magnetic force vector.



5. **Represent.** Continue with the south pole of the magnet upwards. Switch the leads of the battery, reversing which one was connected to the positive and the negative terminals. Close the switch. Observe. Open the switch.
   (a) Draw arrows showing the direction of the magnetic field, the direction of the electron current flow, and the magnetic force vector.



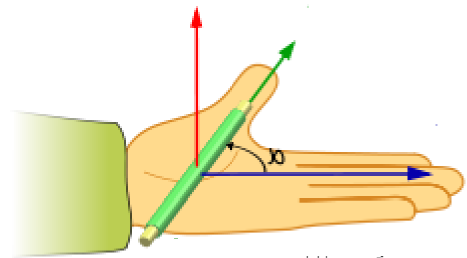
6. **Find a Pattern.** Based on your observations, what characteristics of our set-up can we change that will affect direction of the force experienced by a wire in a magnetic field.

7. **Find a Pattern.** In the three situations we have explored, what is the angle between the directions of the magnetic field, the electron current and the magnetic force?

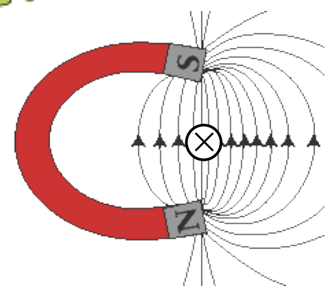
C: The Motor Principle

Charged objects moving perpendicular to a magnetic field will experience a magnetic force. This idea is called the *motor principle*, since it is the phenomenon responsible for making electric motors work. Charged objects at rest in a fixed magnetic field do not experience any force.

The relationship between the direction of the magnetic field, the current and the force can be shown by using the left-hand rule for the motor principle. Stretch out your left hand flat. The direction of your fingers corresponds to the direction of the magnetic field lines (from north to south). The direction of your thumb shows the current and the direction of you palm gives the force.



1. **Apply.** A horseshoe magnet has a very strong field in the space between its two poles. Use the left hand rule for the motor principle to predict the direction of the force acting on a wire with electron current flowing into the page. Draw a magnetic force vector ($\vec{F}_m$) showing the force on the wire.



2. **Predict.** Your teacher has set up a power supply, hanging wire and horseshoe magnet. Examine the equipment. Draw a diagram showing the magnet and its field, the wire and its current flow, and your prediction for the magnetic force.

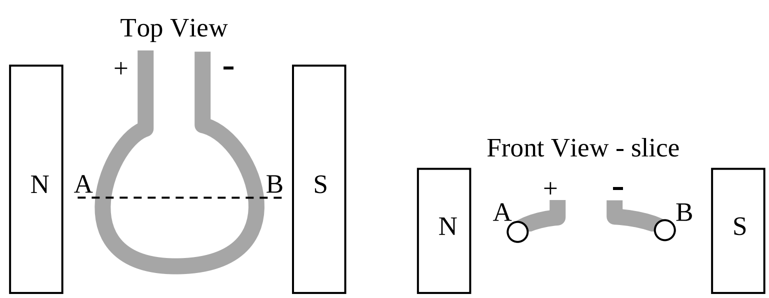
3. **Test.** Make sure the equipment is set up according to the diagram you made for your prediction. Turn on the power. Observe. Turn off the power. Record your observations.

D: Get Your Motor Runnin'

Now we will imagine placing a loop of wire into the magnetic field between two ceramic magnets that are attracting each other. Since this is a three dimensional situation, we will draw this carefully. We draw a dashed line through the loop to show the imaginary slice we take that allows us to picture the electron current flow from different perspectives.

1. **Represent.** Draw the direction of the electron current flow at points A and B in each diagram. (Hint: in the top view you can draw arrows and in the front view you can draw in/out of page vectors)

2. **Represent.** Use the left hand rule for the motor principle to determine the direction of the magnetic force acting on the loop at the two points A and B. Draw these force vectors on each diagram.



3. **Predict.** This is an interesting situation! How do you think the loop will move? Describe this from the front view perspective.

4. **Test.** There is a test loop of wire set up similar to your diagram. Connect the battery and observe the motion. Does this test support your prediction?

SPH3U: Good Vibrations

Recorder: ______________________
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Speaker: ______________________
0 1 2 3 4 5

A: Oscillations and Amplitudes

You will need: a spring and a small object (100 - 200 g). Hang the spring from the edge of your table. Attach your object to the bottom of your spring - a small piece of tape might help.

1. **Observe.** Give the object a small downwards pull and release it (gentle!). Describe the motion of the object. What is different about this motion compared to other motions we have studied in Gr. 11 physics? Briefly note your ideas on a whiteboard.

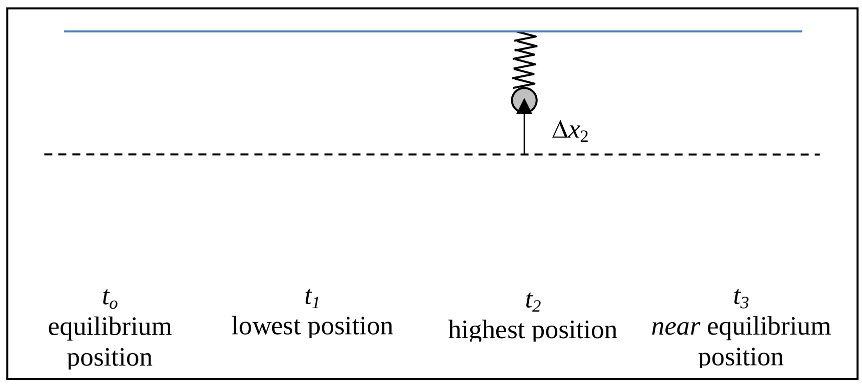
We say that an object moving this way is vibrating or better, *oscillating*. Periodic or oscillatory motion is motion that repeats itself in a regular cycle or pattern. The displacement of the object is measured relative to it *equilibrium position*, which is the position the object would have if it was not in motion.

2. **Observe.** Measure how high above and below the equilibrium position the object oscillates (at least initially). How do these compare? With an ideal spring, these values would remain constant.

The largest displacement of the object from the equilibrium position is the *amplitude* of its oscillatory motion.

3. **Represent.** In the diagram to the right, draw three images of the spring and moving object at the indicated moments in time.

4. **Represent.** Draw a vector for each moment in time carefully showing the object's displacement from the equilibrium position.



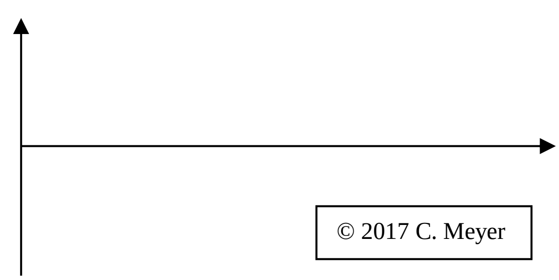
B: Cycles and Periods

A *cycle* is one complete oscillation, starting and ending at the same position after completing one whole motion. The time to complete one cycle is called the *period* (T).

1. **Reason.** A student wants to time the period of your object's oscillation. He suggests, "I think we should start the timer when the object is at the equilibrium position, watch it go down to its lowest position, then back up to the equilibrium position and stop the timer." Do you agree or disagree? Explain.

2. **Observe.** Measure the period of your object's oscillations. Explain what a good technique would be to get a very reliable result.

3. **Represent.** On a graph of displacement vs. time, plot five points that correspond to (a) the highest position, (b) the equilibrium position, (c) the lowest position, (d) the equilibrium position, and finally back to (e) the highest position. How do you think these points will each be separated in time? Interpolate what you think the rest of the graph *between* these points might look like.



4. **Observe.** Use the motion detector set up at the front to plot the position-time graph for the oscillating object. **Neatly** sketch the result for a number of periods of time. Based on the computer measurements, what is the amplitude and period of the oscillation?

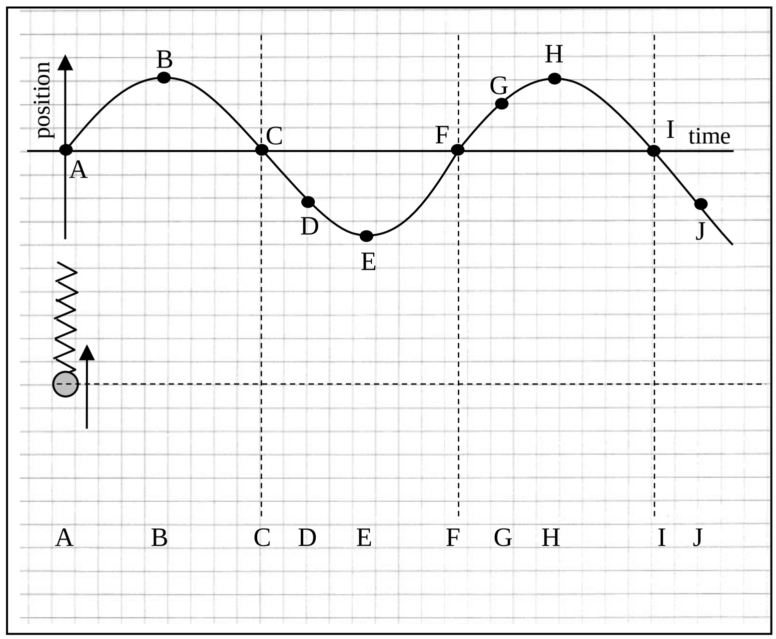
5. **Represent.** Choose two points on the graph at different positions. Use horizontal arrows to indicate one complete period of motion, starting from each of those points.

6. **Reason.** According to the computer observations, roughly how many cycles does your object go through in one second of time?

The *frequency* of periodic motion (*f*) is the number of cycles of the motion per unit of time. This quantity is given by the expression: $f = (\# \textit{ of cycles})/\textit{time}$. The units of frequency are *hertz* (Hz) and mean "cycles per second". Frequency and period are related by the expression: $f = 1/T$ or $T = 1/f$.

C: Phase

Consider the graph to the right showing the position vs. time for an oscillating object.



1. **Represent.** Draw the position of the object and spring according to the graph for each moment in time labeled in the diagram below.

2. **Represent.** Draw an *instantaneous* velocity vector beside each image of the object. If it is zero, write a zero.

The *phase* of a particle in periodic motion indicates its *state* at one moment in time. The particle's state can be described by its position and velocity. Phase is most often used for making comparisons. When two states are identical, they have *equal phase* or are *in phase*. Otherwise they are *out of phase*. When two states are half a cycle apart they have *opposite phase*. Note that the expression *out of phase* is commonly used to mean *opposite phase*. Be careful!

3. **Apply.** Find all the points which have the same phase as:
   B:
   C:
   D:

4. **Reason.** A student says, "I think points A and C have the same phase." Do you agree or disagree? Explain.

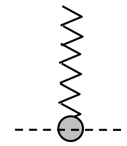
5. **Apply.**Find all the points that have the opposite phase as:
   A:
   B:
   D:

6. Apply. Each person in your group represents an independently moving particle. Figure out how each person should move to illustrate particles that are *in phase*, *opposite phase*, and *out of phase*. No copying other groups! **Show your teacher.**

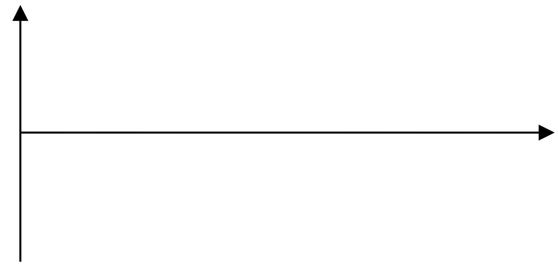
SPH3U: Good Vibrations Homework Name:

A: The Follow the Bouncing Ball

A ball attached to a spring. You pull down the ball and release it. It vibrates up and down with a steady, repeating motion. You measure that it takes 0.73 s to complete one cycle of its motion. During that time, the farthest distance it travels from the equilibrium position is 5.7 cm.



1. **Represent.** Draw a position-time graph for the ball starting at the moment you release the ball. Label and give the values for its period and amplitude.



2. **Calculate.** What distance does the ball travel in one cycle? What is its average speed?

3. **Calculate.** What is the displacement of the ball during one cycle? What is its average velocity?

4. **Reason.** At which moments is the ball traveling the fastest? The slowest? Explain how you decide. (Hint: This is a position-time graph!)

5. **Calculate.** What is the frequency of the ball's motion?

B: The Teeter-Totter

Who doesn't like playing on the teeter-totter in the local park? Two kids are bouncing away and you measure that they bounce up and down 10 times in 17.9 s.

1. **Calculate.** What is the period and frequency of their motion?

2. **Reason.** Two larger kids get on and start bouncing. The restoring force of the spring in the teeter-totter is roughly the same as before, but the kids are more massive. Use Newton's Second Law to help explain what happens to their acceleration. How do you think this would affect the period of their oscillation?

3. **Reason.** With the new, older kids, the period of the teeter-totter is now double what it was before. Explain (don't calculate) how the frequency will change.

4. **Reason.** How does the phase of the two kids who are bouncing together on the teeter totter compare with one another?

A: #2. 22.8 cm, 31.2 cm/s, #3. 0, 0, #5. 1.37 Hz, B: #1. 1.79 s, 0.559 Hz

SPH3U: Making Waves

Recorder: ______________________
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0 1 2 3 4 5

In our work so far, we have had only one particle to keep track of. Imagine now that we connect a whole series of particles together such that the movement of one particle affects the others around it. When we start a vibration in one particle, an effect will travel from one particle to the next – a *wave* has been created. The *medium*, modeled by our set of particles, is the material substance that the wave travels through, for example: water, air, strings, the earth and so many more!

A: Wave and Particle Motion

Your teacher has a wave machine set up at the front of the class.

1. (*as a class*) Describe the motion of the pulse in the wave machine.

2. (*as a group*) Watch one particle carefully as the pulse travels by it. Compare the direction of a particle's motion (the rod) with the direction of the wave pulse's motion. Draw a simple illustration of this.

In a *transverse wave*, the particles of the medium oscillate in a direction that is perpendicular to the direction of the wave motion.

3. (*as a group*) Since no particles move horizontally, what does? What is actually travelling back and forth in this medium? Make a guess and move on.

4. (*as a class*) What is a wave?

Understanding wave versus particle motion. To help you with the next few questions (and the rest of the unit) always ask yourself: "am I focusing on the motion of the wave as a whole, or the motion of an individual particle in the medium?"

5. A "snapshot" of a transverse pulse travelling through a wave machine is shown in the diagram to the right. The pulse is traveling to the right at 50 cm/s. Three particles in the medium are marked with tape, A, B, and C. Each square in the diagram is 5.0 cm.
   (a) Between 0.0 s and 0.1 s, in what direction did each particle move?

   (b) In what direction did the "peak" of the wave move? How far did it travel?

   (c) Draw the pulse and label the position of the three particles at the time of 0.2 s.

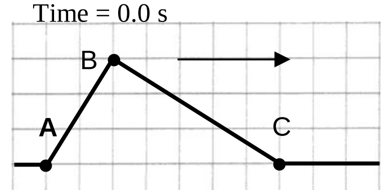
   (d) At what time will the complete pulse have passed through particle C?

   (e) What is the total distance that particle C will move by the time the pulse completely passed?

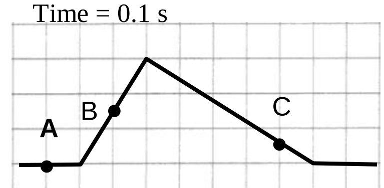
   (f) At what time will particle B return to the rest position?

   (g) What is the average velocity of particle B between t = 0 s and t = 0.1 s?

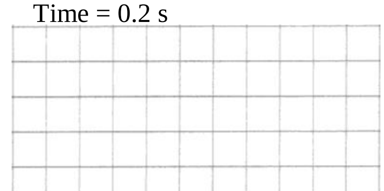
Time = 0.0 s



Time = 0.1 s



Time = 0.2 s

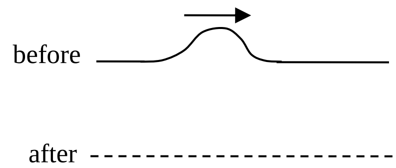


Adapted from *Activity-Based Tutorials,* by Wittmann, M., et al. John Wiley, 2004

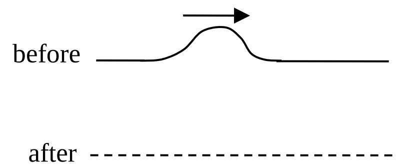
B: The Reflection of Pulses and Waves

Waves don't just disappear when they reach the end of the medium - they reflect and travel back in the opposite direction. But the details of this depend on the *boundary condition* at each end of the medium. The particles at the end of a medium can either be *fixed* or *free* to move.

1. (*as a group*) Your teacher will help you with these observations. A positive pulse (a crest) travels through the medium. Carefully observe the shape of the pulse before and after it reflects off the end of the medium. Sketch a diagram. Describe how the shapes compare.



2. Now we will hold one end of the wave machine fixed (a fixed end boundary condition). A positive pulse travels through the medium. Carefully observe the shape of the pulse before and after it reflects off the end of the medium. Sketch a diagram. Describe how the shapes compare.



3. In which situation would you say the pulses or waves reflect *in phase* and in which situation would you say they reflect in *opposite phase*. Explain.

C: The Periodic Wave and Wave Pictures

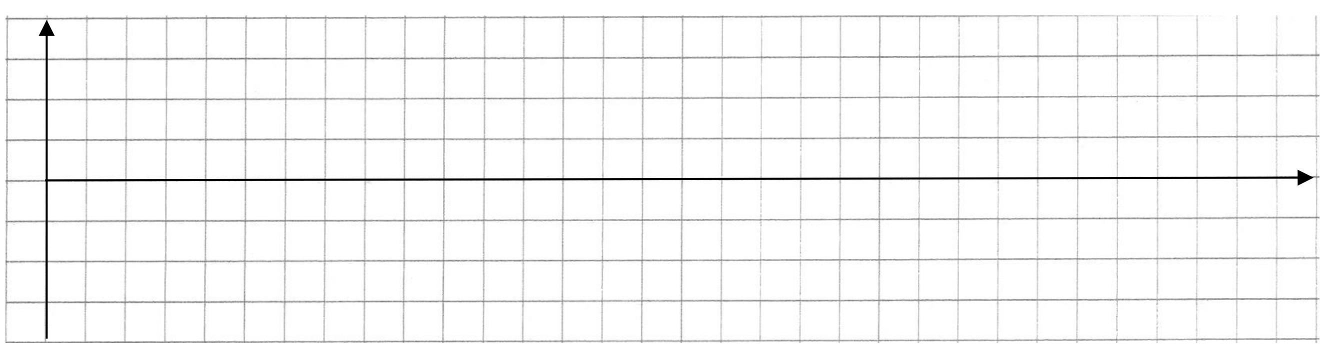
We will use a simulator to make our next set of observations. It will run on most computers and phones. Google "PhET string". Start it up and select "Oscillate" and set Damping = none.

A continuous or *periodic wave* has two parts that we call the *crest* and *trough* of the wave which correspond to the top of the positive and bottom of the negative displacements.

1. **Play.** Experiment with the simulator and try our different settings. Please make sure each person in the group has a chance to use the simulator.

The distance a wave travels in the time of one cycle is equal to the distance between the two nearest points of equal phase. This distance is called the *wavelength* and is represented by the greek letter *lambda* (λ). To measure such a distance, it is often convenient to choose two adjacent crests as the nearest points of equal phase.

2. **Observe.** Reset the simulator. Select "Oscillate" and set Damping = none. Pause the simulator at a moment in time when you have a good set of waves. Select the "ruler" tool and measure the amplitude and wavelength of your wave. Record these values on the graph below.



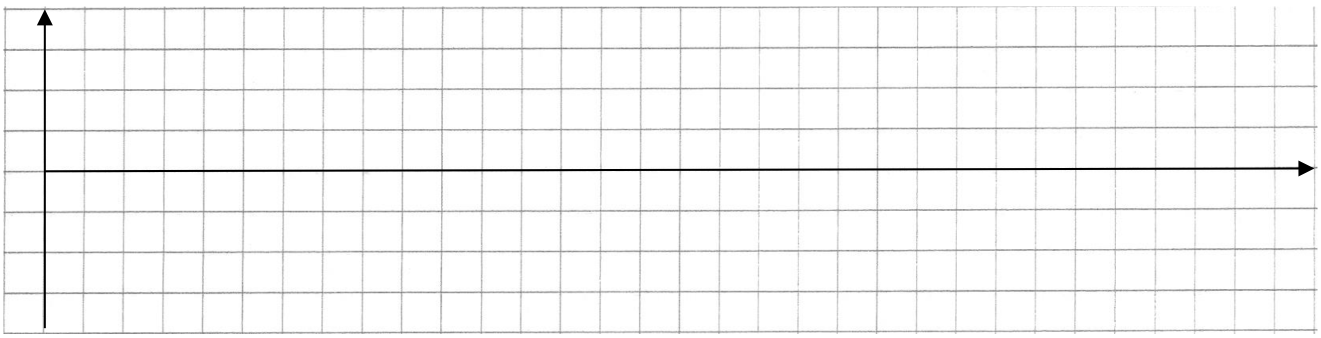
Imagine taking a photograph of a periodic wave. From such a picture we can create a graph showing the position of all the particles in the medium at *one moment in time*. We will call this the *position graph* of a wave because position is graphed on both the horizontal and vertical axis.

3. **Reason.** Label the two axes of your graph on the previous page.

Imagine we track the position of a single particle over time as a periodic wave travels through the medium. We can construct a graph showing the position of the particle as time goes by. We will call this the *time graph* of a wave.

4. **Observe.** Choose one particle in the medium (the green bead, for example) and measure the period of its oscillations. Describe how you do this. Measure its amplitude as well.

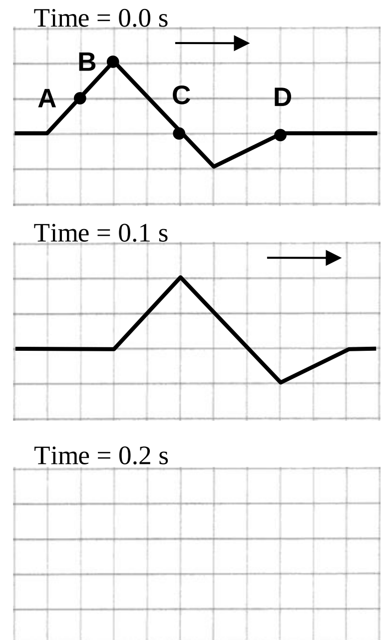
5. **Represent.** Draw a time graph for this particle in your wave Label the two axes, and the amplitude and period measurements on the graph.



SPH3U: Making Waves Homework Name:

A: Tracking the Particles

A pulse travels through a spring as illustrated in the diagram to the right. Four particles of the spring are labeled A, B, C and D. (Imagine a piece of tape is attached to label those particles.) Each box of the gird represents a distance of 5.0 cm.



1. **Represent.** The pulse is shown in the second diagram at a time of 0.1 s after the first. Label the four particles A, B, C and D in the second diagram.

2. **Calculate.** What is the speed of the wave?

3. **Interpret.** What distance did particle B move in the time interval between 0 and 0.1 s?

4. **Interpret.** At the time of 0 s, what direction is particle A moving in? particle C?

5. **Represent.** Draw the pulse at a time of 0.2 s. Label the four particles A, B, C and D.

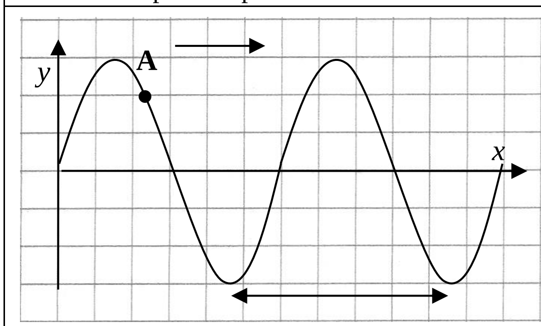
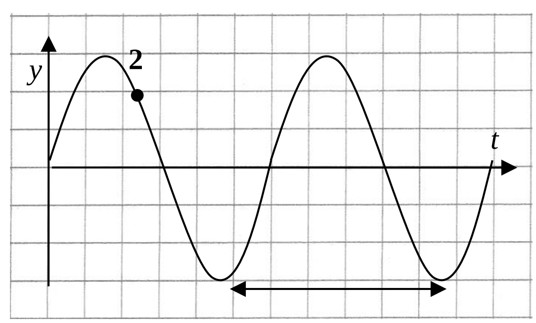
6. **Calculate.** At what time does the pulse completely pass through particle D?

7. **Calculate.** What distance had particle D traveled once the pulse has completely passed by?

8. **Explain.** Explain why this is a transverse wave.

B: Wave Pictures

The position graph and time graph of a wave can appear deceptively similar. Compare the two "identical" graphs shown below.

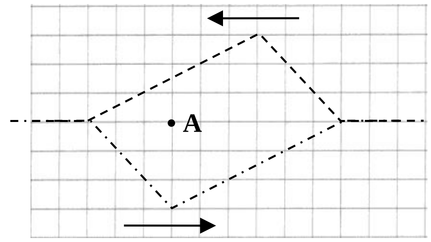
Position Graph – snapshot of wave	Time Graph – motion of particle A
	

1. **Interpret.** The arrows in each picture indicate an interval. What quantity does each arrow indicate? Explain why.

2. **Interpret.** In the position picture, the point shows the *y*-position of a particle which we will label particle A. In what direction is particle A moving at this moment in time? Explain how you can tell.

3. **Interpret.** In the time picture, point 2 represents the *y*-position of particle A at moment 2. In what direction is particle A moving at this moment in time? Explain how you can tell.

SPH3U: Interference Homework Name:



1. The graph to the right shows two wave pulses travelling in opposite directions and interfering.

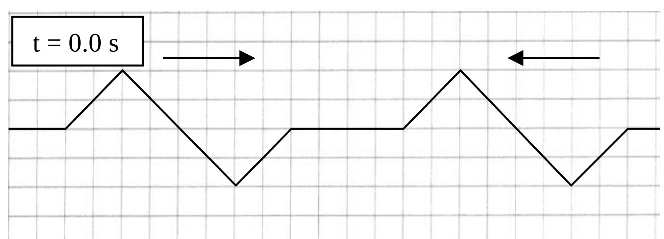
   (a) **Explain.** When these two pulses interfere, do you expect them to completely cancel out (completely interfere destructively)?

   (b) **Calculate and Explain.** Consider point A along the actual medium (point A is showing the position in the medium, not the displacement of the interfering waves). Use the superposition principle to explain how to find the position of that particle in the medium when the two waves interfere.

   (c) **Calculate.** Use the superposition principle to find the position of all the particles in the medium when the two waves interfere as shown. Draw this on the graph above.

   (d) **Calculate and Explain.** The speed of a wave in this medium is 10 grid boxes/second. Starting at the moment shown above, how much time will take for the waves to pass through each other and no longer interfere? Explain your answer.

2. Two waves travel in opposite directions towards one another. Waves in this medium travel with a speed of 8 grid boxes/second.



   (a) **Calculate**. At what time will the two waves begin to interfere?

   (b) **Represent and Explain.** Draw the two separate waves using dashed lines at a time of 0.50 s. Draw the displacement of the medium at this moment in time. What type of interference is occurring?

   (c) **Represent and Explain.** Draw the two separate waves using dashed lines at a time of 0.75 s. Draw the displacement of the medium at this moment in time. What type of interference is occurring?

SPH3U: Interference

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

What happens when two waves travel through the same medium and meet?

A: When Waves Meet

1. (*as a class*) **Observe.** What happens when two similar pulses meet? Observe the results. Record your observations at the two moments in time when the pulses are overlapping and a bit after.

Before	Overlapping	After
Two crests 		

2. **Discuss.** (*as a group*) What are some possible (crazy) ideas that explain what happens to the pulses *after* they meet? You will share these with the class.

3. **Hypothesize.** Create two hypotheses that attempt to explain what happens to the pulses after they meet.

   Hypothesis #1:

   Hypothesis #2:

4. **Design.** Create a testing experiment that will help decide which hypothesis is correct. Describe this experiment.

5. **Predict.** Draw the pulses of your testing experiment before they meet. Use each hypothesis to determine the appearance of the pulses after they meet.

Testing Experiment Pulses Before	Prediction: Hypothesis 1	Prediction: Hypothesis 2

6. **Observe.** (*as a class*) Perform the testing experiment. Record your observations.

7. **Evaluate.** Describe the conclusions of our experimental results.

8. **Observe.** It is very difficult to see what happens when a crest meets an equal sized trough. Watch the video and record your observations when the pulses overlap and after they have overlapped.

Before	Overlapping	After

When two ideal waves overlap, one does not in any way alter the travel of the other. While overlapping, the displacement of each particle in the medium is the sum of the two displacements it would have had from each wave independently. This is the *principle of superposition* which describes the combination of overlapping waves or *wave interference*. When a crest overlaps with a crest, a *supercrest* is produced. When a trough and a trough overlap, a *supertrough* is produced. If the result of two waves interfering is a greater displacement in the medium *constructive interference* has occurred. If the result is a smaller displacement, *destructive interference* has occurred.

B: Interference Frozen in Time

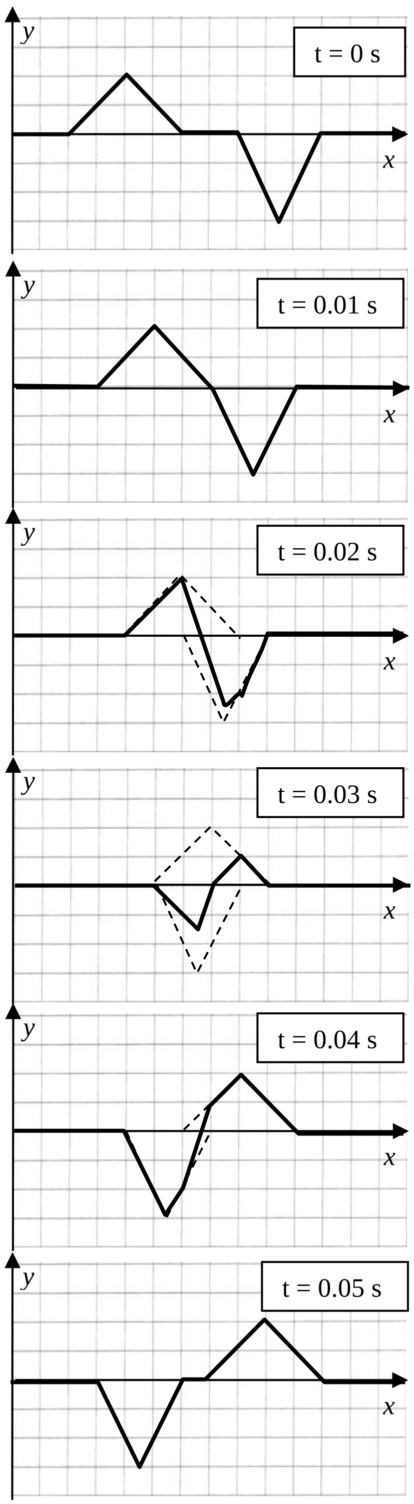
Let's apply the principle of superposition to some sample waves and learn how to predict the resulting wave shapes. Each pulse moves with a speed of 100 cm/s. Each block represents 1 cm. A sample of the interference process is shown in the first column of diagrams.

1. Study the sample process shown in the column of diagrams to the right. Draw an arrow on the first diagram showing the direction in which the pulses are travelling.

2. At what time do the pulses begin to interfere? At what time do they finish?

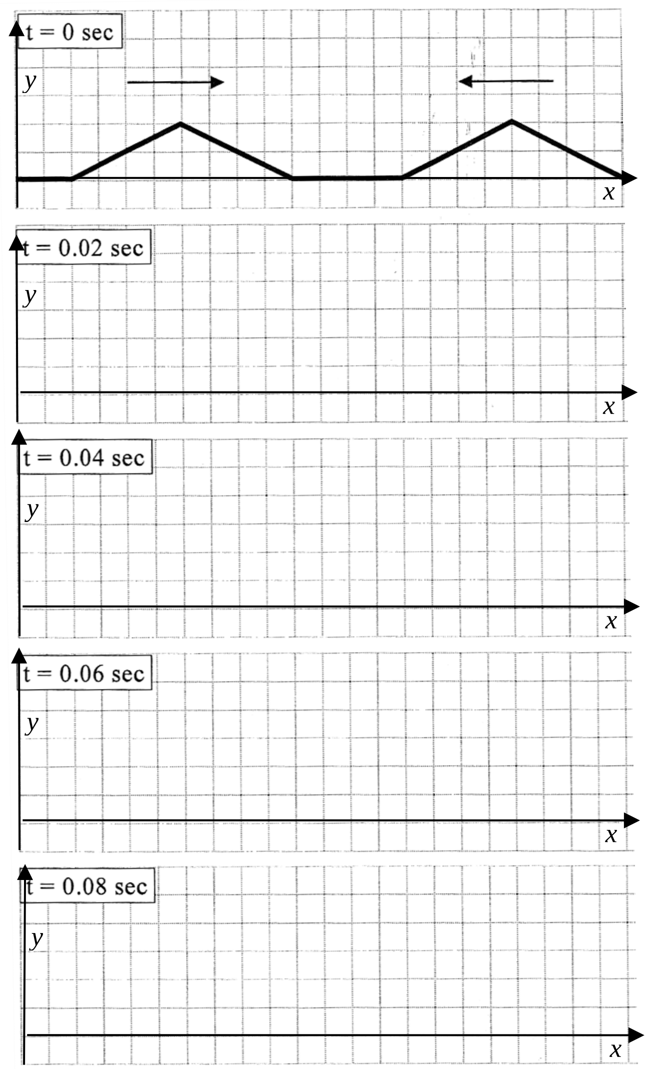
3. At t = 0.03 s, what type of interference occurs?

4. At t = 0.03 s, use the superposition principle to explain how to calculate the resulting wave shape.



1. The second column of diagrams below is an example for you to try. How many boxes will each pulse travel between each diagram?

2. Complete the set of diagrams. Show the positions of the individual pulses with dashed lines and the resulting wave shape with a solid line.



C. Meyer 2014, and *Activity-Based Tutorials,* by Wittmann, M., et al. John Wiley, 2004

SPH3U: The Speed of Waves

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

A: Ideal Waves and Pulses

Real waves and pulses can be very complex. As a real wave or pulse travels or *propagates* through a medium it may gradually change.

1. **Observe.** (*as a class*) Use the wave machine to create a single pulse. Describe how the pulse changes while it travels back and forth through the medium.

Real waves lose energy as they travel causing their amplitude to decrease. The shape of a pulse also changes – often spreading out. In our model of mechanical waves, we will always assume that waves do not lose energy or change shape as they travel. We will call this the *ideal waves* assumption.

B: The Speed of a Wave

There are three important characteristics of a pulse that we can easily control: the height (amplitude), the width (wavelength or period) and the shape (waveform – more about this later). We will make pulses with different heights and widths and see how these characteristics affect the speed of the wave.

1. **Observe.** (*as a class*) Make a pulse which will be your "standard" pulse. Get a feel for how quickly it travels back and forth through the medium.

2. **Observe.** We will vary the pulse in a number of different ways and make a rough judgment – does it appear to travel back and forth faster, slower or the same?

3. **Summarize.** How do the characteristics of the pulse affect the speed of the wave?

Pulse Description	Observations
Large amplitude	
Small amplitude	
Long wavelength	
Short wavelength	
Funny shape	

The speed of a pulse or wave does not depend on the amplitude, shape or period (or frequency). It only depends on the physical properties of the medium, such as density, tension and variety of other factors.

C: Wave Speed in a Coiled Spring

We will use a coiled spring to study the motion of ideal wave pulses. If there is no space in the classroom, you will need to do this in the hallway. **The spring must always remain in contact with the ground! Never let go of the spring while it is stretched! Be sure it does not get tangled up!** Stretch the spring enough so you can clearly see a wave make a complete trip back and forth. You will need a measuring tape and stopwatch.

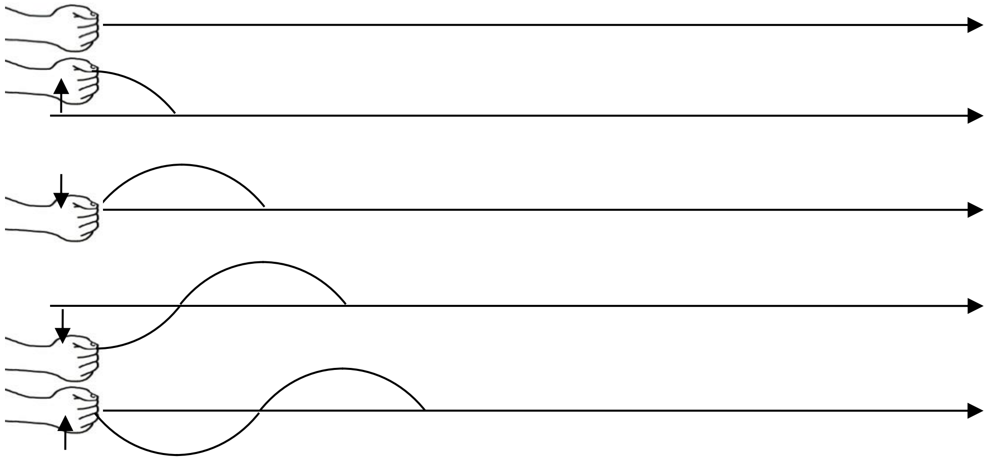
1. There is one characteristic of this medium (the spring) that we can easily change – the tension. Increase the tension and determine the wave speed. Use a medium spring scale.

2. Describe roughly how tension affects the wave speed.

Tension	Distance	Time	Speed

D: Speed, Wavelength and Frequency

How is the speed of a wave related to its frequency and wavelength? Let's think this through. The diagrams below show your hand which moves up and down with a fixed frequency as it generates a wave.



1. Study the motion of your hand in the diagram. What fraction of a cycle does your hand move through between each picture?

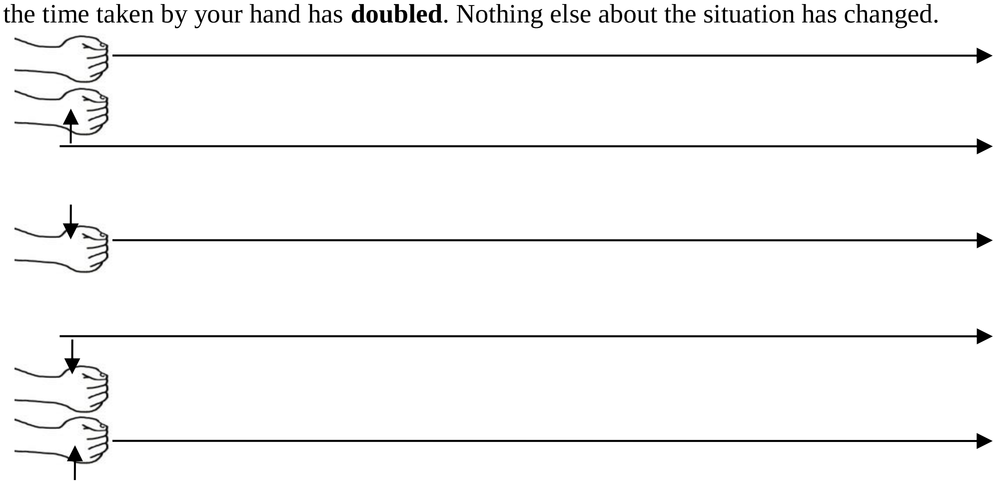
2. What do we call the time interval for the motion of your hand in this diagram?

3. What fraction of a wavelength do we see in each diagram? Label these lengths.

4. How far does a wave travel in the time of one period? What is the special name for this distance?

5. How could we find the actual wavelength of this wave if we knew the period (0.5 s) and the wave speed (4.7 m/s)? Construct an equation using the symbols v, T and λ.

Now you generate another wave, but the time taken by your hand has **doubled**. Nothing else about the situation has changed.



6. How will the **frequency** of your hand (and the wave) compare with the previous example?

7. How will the wave speed compare with the previous example?

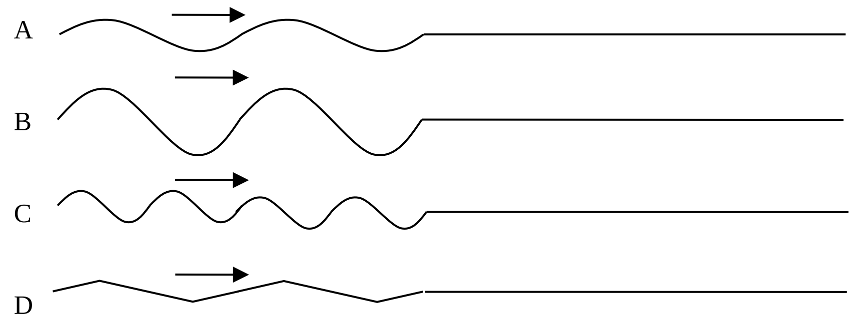
8. How will the distance travelled by the wave during your one cycle of your hand's motion compare with the previous example? Sketch this in the diagrams above. Label your diagrams like the previous example.

9. Describe how frequency affects the size of the wavelength. Be as precise as possible.

The *universal wave equation,* $v = f\lambda$, relates the frequency and wavelength of a wave to the wave speed in a given medium. Note that a change in frequency affects the wavelength and vice versa, but **do not affect the wave speed**. The wave speed only depends on the physical properties of the medium.

SPH3U: Speed of Waves Homework Name:

1. **Reason.** Four different waves travel along four identical springs as shown below. All begin travelling at the same time.
   (a) Describe what is different about each wave.



   (b) Rank the amount of time it will take for the four waves to arrive at the ends of the springs. Explain your reasoning.

2. **Reason.** Your friend is sending a wave along a spring and says, "I want the wave to reach the other end of the spring in less time, so all I have to do is shake my hand faster." Do you agree with your friend? Explain.

3. **Represent.** You have a spring stretched out 7.3 m along the floor between you and your friend. You shake your hand side-to-side and create a wave that travels down the spring. Your hand starts at the equilibrium position and moves 10 cm to the right, back to the equilibrium, 10 cm to the left and back to the equilibrium position. Your hand executes this three times in a row in 1.2 seconds. Your friend times that it takes 0.84 s for the wave to travel from your hand to your friend's.
   (a) **Represent.** Sketch a graph for the wave. Label all the quantities in the description.

   (b) **Calculate and Explain.** What is the period of this wave? Explain how you chose which time values to use.

   (c) **Calculate and Explain.** What is the speed of the wave in this spring? Explain how you chose which distance and time values to use.

   (d) **Calculate and Explain.** What is the amplitude of the wave? Explain how you chose which distance values to use.

   (e) **Calculate and Explain.** What is the wavelength of this wave? Explain how you chose which values to use.

   (f) **Calculate and Explain.** What distance does a particle in the wave move once the wave has passed by?

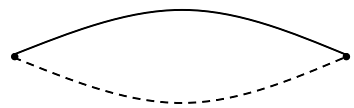
   (g) **Represent.** Label all the quantities you calculated on your sketch above.

SPH3U: Standing Wave Homework Name:

A: Thinking About Standing Wave Patterns

1. **Explain.** Why is there a node at each end of the stranding wave diagrams we drew for our spring in class?

2. **Explain.** We decided that the first mode or standing wave pattern had a length of just half a wavelength. Explain how we can tell. Sketch the complete wave.



Another label used to describe which mode (standing wave pattern) a medium is vibrating in is the *harmonic*. We say that a spring vibrating in its *first harmonic* when it is vibrating in the simplest possible standing wave pattern (the least number of nodes)..

B: Pure as the Driven Spring

A spring is stretched out and held fixed on the ground at two points 2.9 m apart. Its wave speed at that length is 4.5 m/s.

1. **Calculate and Explain.** What is the wavelength when vibrating in the first and second harmonics? Explain your result.

2. **Calculate.** What frequency should the student use to create a standing wave in the first and second harmonics?

C: The Wave Machine

The wave machine behaves differently than a spring does. We can create a standing wave by driving the rod at the end of the machine up and down with the right frequency.

1. **Reason.** Is a node or an antinode located at the end of the machine where we are driving a rod up and down? Explain.

2. **Represent.** At the other end of the machine, the last rod moves up and down a great distance. The standing wave diagram for this situation will look quite different from the ones we drew for the spring. Draw the standing wave diagram for the first and second harmonics of the wave machine. (Hint: the first harmonic has only one node.) Label the nodes and antinodes.

3. **Calculate**. The wave machine has a length of 84 cm and a wave speed of 0.93 m/s. What are the wavelengths and frequencies of the first and second harmonic?

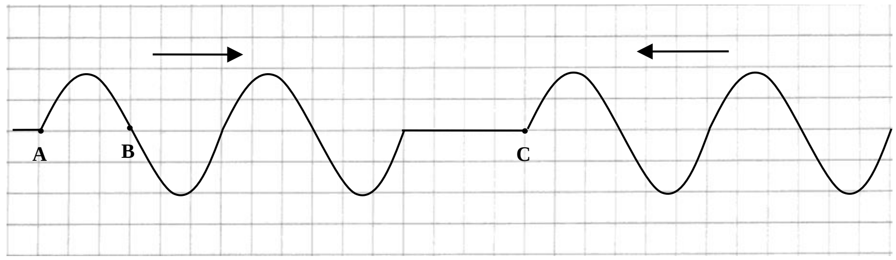
SPH3U: Standing Waves

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

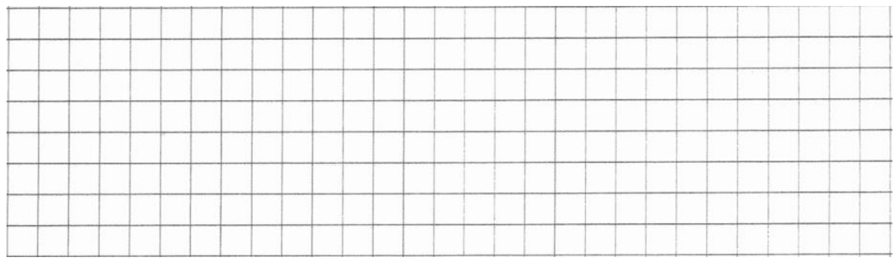
A: When Continuous Waves Interfere

The diagram to the right shows two waves travelling in opposite directions in a spring.

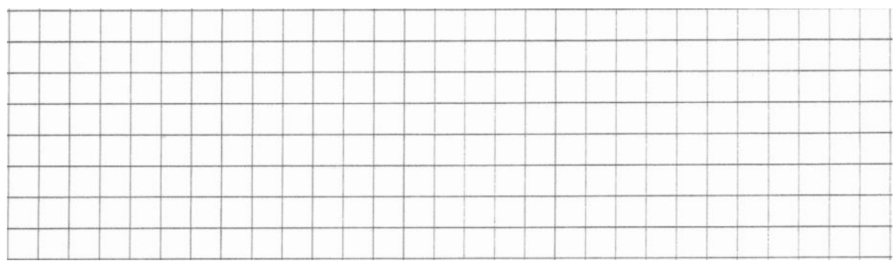
The points A, B, and C are points of constant phase and **travel with the wave**. We will use these to help keep track of the wave.



1. Use dotted lines to draw the shapes of the individual waves when points B and C coincide. Draw the displacement of the actual medium using a solid line. You should be able to do this without detailed math work. Borrow the transparencies of these waves to help visualize this. Label the regions where constructive or destructive interference occurs.



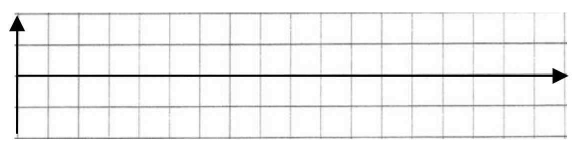
2. Use dotted lines to draw the shapes of the individual waves when points A and C coincide. Draw the displacement of the actual medium using a solid line.



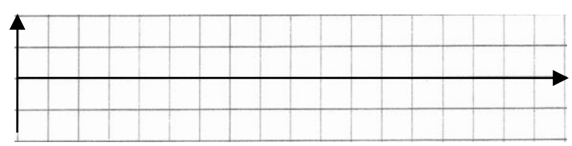
B: Representing Standing Waves

When the interfering process we examined above repeats, a standing wave is created. Your teacher will create a standing wave in a wave machine (or show a video).

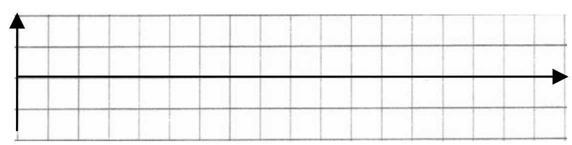
1. **Observe.** Do all particles in the medium oscillate equal amounts? Describe the pattern of oscillations.

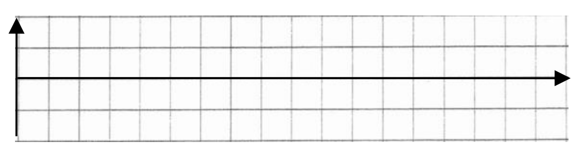


2. **Observe.** Your teacher will freeze the video to help us study the standing wave pattern at different moments in time, separated by ¼ period. Sketch the displacement of the medium at each moment.



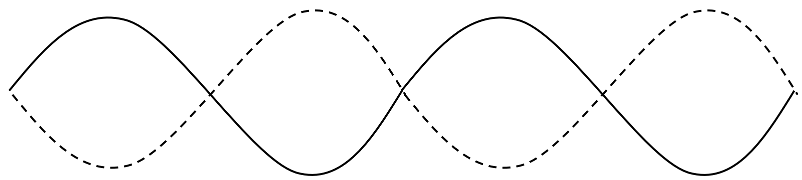
A *standing wave* is a wave pattern created by the interference of two continuous waves travelling in opposite directions in the same medium. It is called a standing wave because we no longer see the individual waves move along the medium. Instead we see some particles in the medium that do not move at all. These particles or locations are called *nodes*. There are other locations where particles move the greatest amount. These locations are called *antinodes*.





3. **Represent.** Label the locations in the medium where nodes and antinodes are found in your sketches. Label each picture by the type of inference that is occurring.

Since a standing wave pattern is a moving phenomena, we need a *standing wave diagram* to represent it. In this diagram, we show the wave at the two moments in time when the greatest displacements occur, as shown below.



4. **Represent.** Label locations in the medium where nodes and antinodes occur in the standing wave diagram.

5. **Reason.** What fraction of a cycle has elapsed between the two images of the wave?

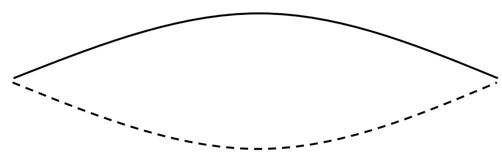
C: Standing Wave Patterns

You need a coiled spring, long measuring tape and a stopwatch. Two people will generate a standing wave in the spring – one will drive it and the other holds their end fixed to the ground. A third person will measure the lengths and time the motion. Stretch the spring so there is a fair bit of tension.

1. **Observe.** The driver will start with a very low frequency and gradually increase the driving frequency until it is as high as possible. Do standing waves occur with every possible frequency? What do you notice?

2. **Observe.** Create a standing wave with the lowest frequency you can manage. You've got the correct pattern if there is only one anti-node. Measure the length of the spring all the way up to the elbow of the person driving it. (That person's arm is like the last bit of the spring). Measure the period of the standing wave. Complete the first row in the chart below.

3. **Observe.** Gradually increase the frequency driving the spring until you find the next standing wave pattern or oscillation mode. Every time, a new node should appear. Measure the period. Repeat this and complete the chart below.

Mode	# of Anti-Nodes	# of Nodes	# of λ	λ (m)	T (s)	f(Hz)	Diagram
1	1	2	½				
2							• •
3							• •

4. **Reason.** Describe the patterns you see in each column when the oscillation mode increases.

5. **Predict.** What is the standing wave pattern and all its characteristics for the 5th mode. Sketch it below.

SPH3U: Resonance

Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

A: The Little Driving Goes a Long Way

Your teacher has a short section of a slinky stretched vertically and fixed at each end.

1. **Observe** (*as a class*). Your teacher will pull the slinky to one side and release it (plucking it). Describe what you observe. Even though it dies away, does the slinky's motion resemble any patterns we have seen before?

If you tap (snap, pluck, hit) an object and let it vibrate freely, it will vibrate most strongly at its *natural frequency*. The natural frequency results from the object vibrating in its simplest standing wave pattern, also known as the *fundamental mode.*

As an alternative to plucking, we can create a vibration using a continuous, periodic (regularly changing) *driving force* applied to the medium.

2. **Observe** *(as a class)***.** Your teacher will hold onto a coil of the spring at different positions and exert a periodic driving force. What is the best position along the medium to exert a driving force and produce a large standing wave pattern?

3. **Observe** *(as a class)***.** When the standing wave is produced, estimate the amplitude of the driving motion (your teacher's hand) and the amplitude of the standing wave. How do these compare?

4. **Represent.** Draw a standing wave diagram for the spring vibrating at its natural frequency. Label the nodes, antinodes and the location you noticed was best for driving the spring.

5. **Observe** *(as a class)***.** Compare the frequency of the driving force and the frequency of the standing wave. Watch again as your teacher changes the frequency of the driving force. What happens to the vibrations if we change the frequency of the driving force by a small amount higher or lower?

A small, periodic driving force can cause an object to vibrate with a large amplitude. This phenomenon is called *resonance*. An object will *resonate* when the *driving frequency* matches one of the object's *resonance frequencies* or *harmonics*. The resonance frequencies (harmonic frequencies) are the frequencies of the different possible standing wave patterns for that particular medium. If the driving frequency is slightly higher or lower than a resonance frequency, the *response* (the amplitude of the vibration) in the object is much smaller and the vibrating pattern will not be regular.

6. **Explain.** Why is the situation we have just observed an example of resonance?

B: Find the Natural Frequency

1. **Observe.** Hang a small mass from the bottom of a short segment of your spring. Give it a downwards pull and release it (a pluck). Describe what you observe. Measure the frequency that it naturally vibrates at.

2. **Reason.** What characteristics of your spring-mass system could you change so it vibrates at a different natural frequency? What about changing the size of your downwards pull? (observe this carefully!)

3. **Observe.** Hold a metre stick against the surface of your desk with one part hanging beyond the edge. Pluck the free end of the meter stick. What characteristics of the vibrating section of the meter stick can you change to change the natural frequency? Describe what you observe.

4. **Represent.** Draw a standing wave diagram for the vibrating portion of the meter stick after your pluck. Label nodes, antinodes and other measurements you made.

5. **Reason.** What fraction of a wavelength is illustrated in your standing wave diagram? Label this by indicating that the length (L) of the vibrating section is equal to some fraction of λ

6. **Observe.** Now hold the middle of the meter stick tightly across the corner of your desk. Pluck one end. Describe what you observe. Measure the length of the vibrating system.

7. **Represent.** Draw a standing wave diagram for the meter stick after your pluck. Label nodes, antinodes and other measurements you made.

8. **Reason.** What fraction of a wavelength is illustrated in your standing wave diagram?

C: Wine Glass Resonance

1. **Observe.** You will use a wine glass at the front of the classroom. Gently tap the side of the glass. You hear a sound which corresponds to the glass vibrating at its natural frequency.

2. **Observe.** Wet the tip of your finger. Slowly and gently rub it around the rim of the glass until you hear a sound. How does the frequency of the sound (the pitch) compare with the ding you heard when tapping it?

This is an example of resonance. Your wet finger skips across the edge of the glass providing the driving force and causing the wine glass to vibrate at its natural frequency.

3. **Predict.** What could you do to change the natural frequency of the glass? (Hint: think of water!) Make a prediction: How would the change you describe affect the natural frequency?

4. **Test.** Test this out. Describe your results.

SPH3U: Resonance Homework	**Name:**

An object can resonate at the frequency of any standing wave that can form in the object. This set of frequencies or *harmonics* is called the *harmonic series* for that object.

1. You have a spring stretched along the floor to a length of 3.9 m.
   (a) **Represent.** Draw a standing wave diagram for the first three harmonics (the first three standing wave modes). You may assume that there is a node at each end of the spring.
   (b) **Calculate.** How many wavelengths are found in the length of the medium? What is the size of one wavelength?
   (c) **Calculate and Describe.** Waves travel with a speed of 6.1 m/s in your spring. Determine the first three resonant frequencies for your spring. What do you notice about the pattern of frequencies?

	Standing Wave Diagram	Length = __ λ	λ	*f*
1		$L = \frac{1}{2}\lambda$	7.8 m	
2				
3				

2. **Represent and Calculate.** You hold one end of a new meter stick against the desk. The length of the vibrating part of the stick is 0.75 m and it vibrates in its first harmonic with a frequency of 5.3 Hz. What are the frequencies of the next two harmonics? (Hint: the wave speed *v* is the same for all three harmonics.)

	Standing Wave Diagram	*L*=__ λ	λ	*f*
1		$L = \frac{1}{4}\lambda$		
2				
3				

To decide whether resonance will occur in a medium, the driving frequency must match one of the possible standing wave frequencies. Another way of thinking about this is the wavelength of the driven wave must match the wavelength of a possible standing wave pattern. We call these ideas the *resonance condition* for a driving force and a medium.

3. **Calculate and Explain.** You create a wave that has a wavelength of 84 cm in a spring stretched out to a distance of 126 cm. You may assume there is a node at each end of the spring. Will resonance occur? (Hint: find the wavelength of the first few harmonics and check if this matches your driven wave).

4. **Calculate and Explain.** The two ends of a spring are held fixed on the ground 1.81 m apart. Waves travel in the spring at 4.7 m/s. A student drives the spring using a frequency of 2.9 Hz. Will resonance occur?

SPH3U: Sound Waves

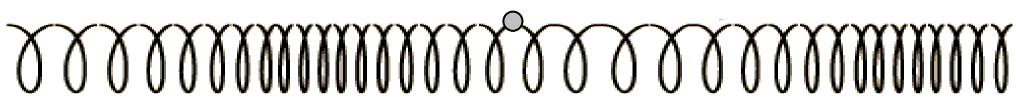
Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

A: Longitudinal Waves

1. **Explain.** All of the waves we have studied so far have been transverse waves. Remind yourself: What is a transverse wave?

2. **Observe.** You need a slinky segment for the next part of this investigation. Stretch it out across your desk. Attach a small piece of tape to a coil near the middle of the slinky. Stretch out the slinky with a fair amount of tension. Have someone pull the coils towards the hand of the person holding down an end. Release the coils and describe what you observe.

3. **Represent.** Illustrate with arrows how the piece of tape moves.

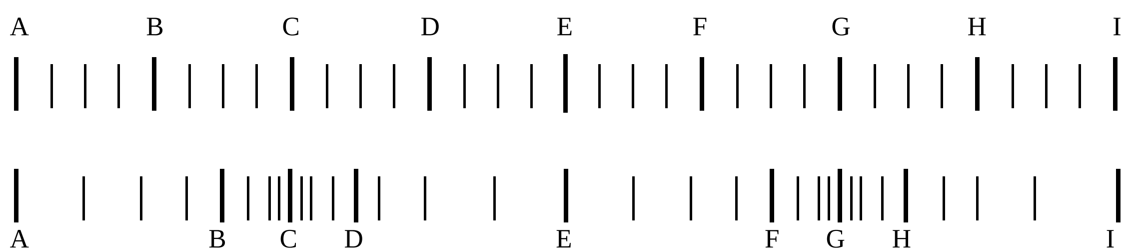


The particles in a *longitudinal* wave move parallel to the direction of the wave pulse. A longitudinal wave will cause some regions of the medium to become compressed, producing a *compression* where the density of the medium has increased. It will also cause some regions to become stretched out, producing a *rarefaction* where the density of the medium has decreased.

4. **Represent.** Label the regions of compression or rarefaction in the diagram above.

5. **Challenge.** Create a longitudinal standing wave in your slinky segment. Move on after a couple of minutes.

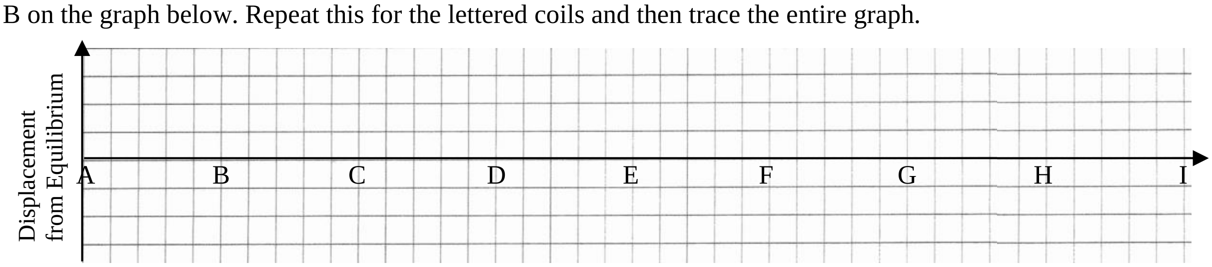
6. There are two images of the coils of a slinky below. The upper image shows the coils of a slinky at rest (in their equilibrium positions). The lower image shows a slinky with a standing wave at one moment in time. Every fourth coil in the slinky has been labeled.



a) **Reason.** Which coils in the second image have not moved from their equilibrium positions? Are these displacement nodes or antinodes? Label them on the image.

b) **Reason.** Use an arrow to draw two examples of the wavelength of this standing wave pattern. Explain how you decide to draw this.

c) **Represent.** Drawing a longitudinal wave the way we did above is challenging. Instead, we will often represent a longitudinal wave using a transverse picture. Label the slinky's nodes on the graph below. In the lower slinky image, is particle B displaced in the positive (right) or negative direction (left)? Draw the positive or negative displacement of B on the graph below. Repeat this for the lettered coils and then trace the entire graph.

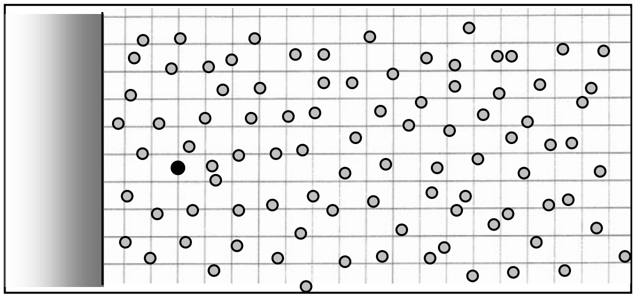


B: The Sound Wave

A *sound wave* is any kind of longitudinal wave that travels through a medium. The sound waves we are most familiar with are those that travel through air. A vibrating object causes a disturbance in the air particles around it and this disturbance travels outwards as a longitudinal wave.

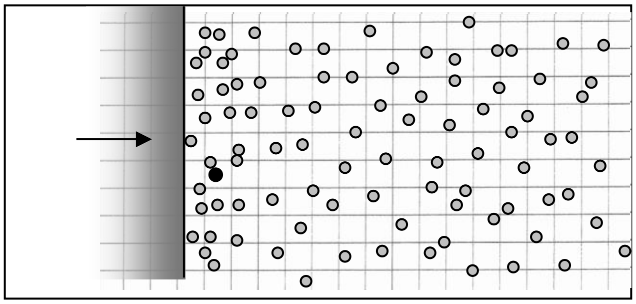
When you put on your ear phones and crank up your mp3 player, a tiny membrane in the earphone vibrates back and forth creating a sound wave in the air near your ears. The diagram below shows the membrane and the air particles, both initially at rest.

1. **Observe.** How do the air particles appear to be distributed?

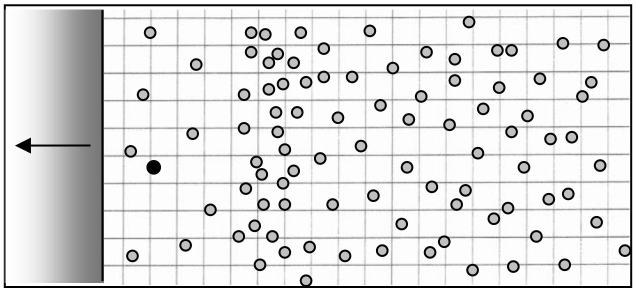


If we could watch a video of these particles, they would be travelling in random directions, bouncing off one another. This is the equilibrium state of the medium of air. When we study longitudinal waves, we will ignore the random vibrations of the air molecules.

2. **Observe.** Now the membrane begins to vibrate. Describe what happens to the spacing of the air particles near the membrane.



3. **Observe.** The membrane now moves in the opposite direction. Describe what happens to the particles near the membrane.



The regions where the medium is compressed have a high air pressure and regions where the medium is rarefied have a low air pressure. Sound is a *pressure wave*. The diagrams above are good illustrations of how a sound wave is created by any vibrating source – not just your headphones!

4. **Represent.** Label the regions of high and low pressure in the diagrams above.

5. **Observe.** One air particle has been emphasized in black. Describe its overall motion. Trace its path on the bottom diagram. How does this motion agree with our understanding that sound is a longitudinal wave?

The regions of high and low pressure travel outwards from the vibrating object. If we could see this, it would look like a spherical shell expanding outwards from the source. The individual air particles **do not** travel any great distance – typically around a billionth of a metre (nm). They simply oscillate back and forth, more or less in place (ignoring the random motions). It is the regions of high and low pressure that move outwards.

6. **Predict.** Isaac holds a tissue near the front of a speaker creating a loud sound. He claims that if he releases the tissue, it will "blow away" due to the sound waves travelling outwards like a wind. You are not sure, but propose an experiment: Put a speaker in a sealed plastic bag. What prediction will Isaac make for what happens to the sound? Will he expect to hear anything? According to our model of a sound wave above, what do you predict will happen? We will test this as a class.

   Isaac:

   You:

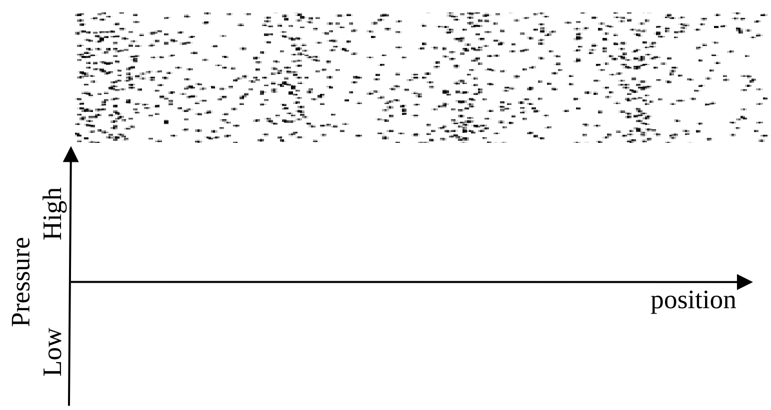
   Result:

C: Representing Sound Waves

Another way to represent longitudinal waves is using pressure. The first diagram to the right shows the air particles involved in a periodic sound wave captured at one moment in time.

1. **Represent.** Label the regions of high and low pressure in the air particles with the letters "H" and "L"

2. **Reason.** Does the interval between two compressions represent the period or wave length in these illustrations? Explain. Label these intervals on the diagrams.



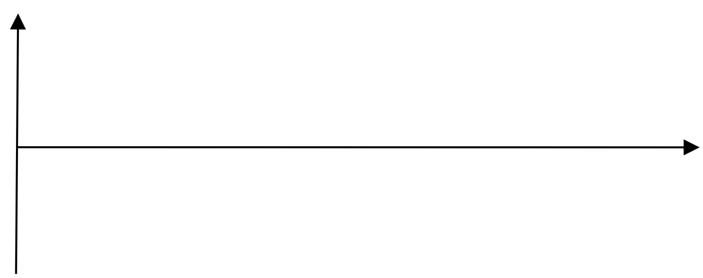
3. **Represent.** Plot on the graph below a data point for each high and low pressure region.

4. **Predict.** The pressure will change smoothly from high to low. What will the complete the graph look like? Sketch this on the graph above.

> A sound wave can be represented on the computer using a microphone. When the high and low pressure regions reach the microphone, they push against the microphone surface. The electronics convert the changing pressure into a changing voltage which the computer can read and display in a graph. We will call this the *pressure graph* of a sound wave. A pressure graph may have either time or position along the horizontal axis, like the earlier graphs we studied.

5. **Test.** Use the microphone attached to the computer to verify your predicted pressure graph for the sound wave created by a vibrating tuning fork. Be sure to strike the fork with a proper mallet or on something soft. Sketch what you observe and label the axes of the graph.

6. **Reason.** In this pressure graph, is the interval between two adjacent crests the period or wavelength of the sound wave? Explain how you can tell. Label these intervals with arrows.

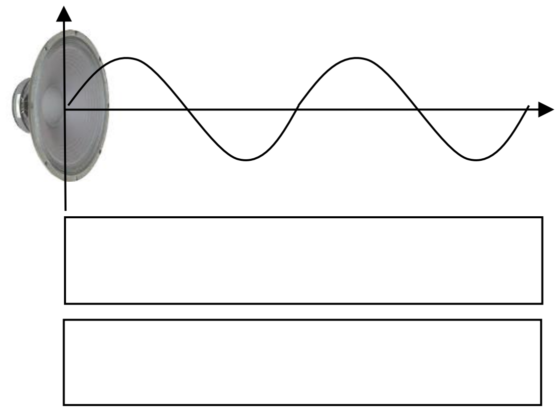


SPH3U: Sound Waves Homework Name:

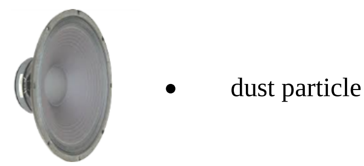
1. A speaker creates a steady sound wave, represented by a pressure-position graph.
   (a) **Represent.** Complete an illustration of the air particles and "slinky-coils" according to this graph.

   (b) **Interpret.** For each diagram, decide whether it illustrates the wave's period or wavelength. Label this on each.

   (c) **Reason.** We increase the frequency of the sound the speaker makes. Explain how the three diagrams will change.

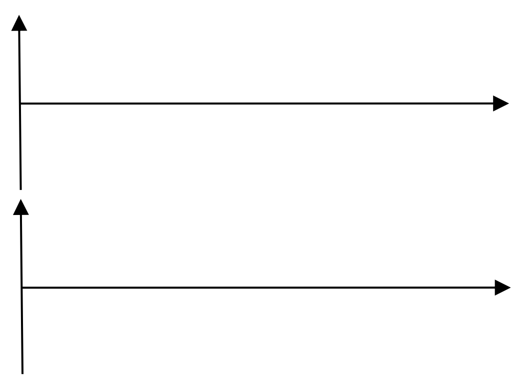


2. A dust particle floats in the air in front of a speaker. The speaker is turned on and produces a sound with a constant frequency and amplitude.
   (a) **Represent.** Describe the motion (including direction!) of the dust particle. Illustrate this on the diagram.



   (b) **Reason.** The frequency and amplitude of the sound are both doubled. What will happen to the motion of the dust particle?

   (c) **Represent.** Sketch a displacement-time graph for the dust particle in each situation above. Label the differences seen in the two graphs.



We can use a *displacement-time* graph to represent the displacement of a particle from its equilibrium position at each moment in time. This type of graph is different from the *pressure* graphs we studied in class. A pressure graph does not show how far a particle has been displaced from equilibrium.

SPH3U: Harmonics Review Name:

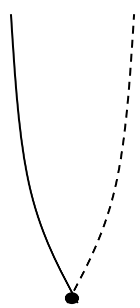
1. A string is stretched out and fixed at both ends. The different standing wave patterns that can form in the string are called the harmonics. Complete the chart below, which describes the different standing wave patterns for string fixed at both ends.

Mode	Sketch	# of Anti-nodes	# of Nodes	# of λ	Frequency Compared to f_o	Harmonic
1		1	2	½	$1f_o$	1st
2						
3						
7						

2. How are the following quantities related to the harmonic?
   a) The number of antinodes b) The number of nodes c) The number of wavelengths

3. In columns of air, the pattern of harmonics is slightly different and this depends on the type of air column. Complete the chart below.

Open-Closed Columns

Mode 1	Mode 2	Mode 3
# of nodes = **1** # of anti-nodes = **1** # of λ = **¼** f = **1 f_o** 	# of nodes = # of anti-nodes = # of λ = f =	# of nodes = # of anti-nodes = # of λ = f =

Open-open Columns

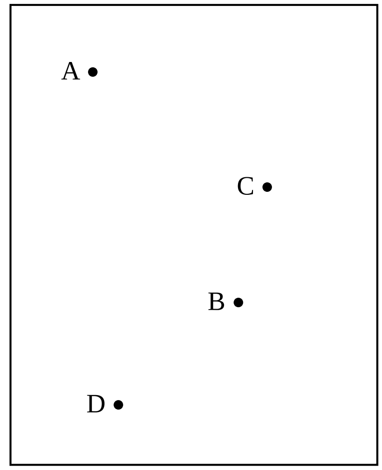
Mode 1	Mode 2	Mode 3
# of nodes = 1 # of anti-nodes = 2 # of λ = ½ f = 1 f_o	# of nodes = # of anti-nodes = # of λ = f =	# of nodes = # of anti-nodes = # of λ = f =

SPH3U: The Propagation of Sound

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

A: Two Dimensional Sound Waves

A student is sitting in a classroom and her cell phone rings! During class! This scandalous event is shown in the diagram to the right. Four students are also shown in the diagram and they are labelled A, B, C, and D. Student B has the ringing phone.



1. Which students can hear the sound from the cell phone? Explain. (There are no obstructions in the room.)

2. Technically speaking, do all the students hear the ring at the same time, or different times? Explain.

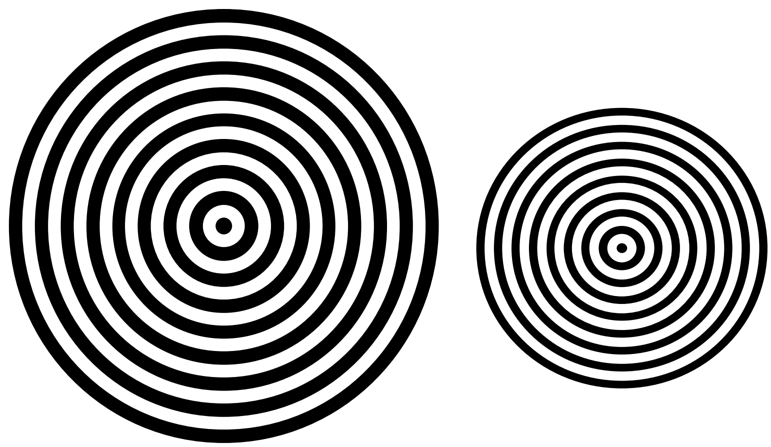
If we could picture a sound wave, we would see a circular wave (well, actually a spherical wave) of compressions and rarefactions travelling outwards from the source. We can represent these regions of compression and rarefaction as circles. For convenience, we will choose to have the dark line represent the crest of the wave (compression).

3. A pure sound tone which has only one frequency will produce a regular, steady series of circles. Two examples are illustrated to the right.
   (a) Use arrows to label the crests (compressions) and troughs (rarefactions).

   (b) What does the distance from one dark band to the next represent?

   (c) Which wave has the higher frequency? Explain how you can tell.

   (d) Which wave has been traveling for the most time? Explain how you can tell.



4. Draw a circle showing a sound wave that has just reached student D. Who has already heard this sound? Who has not heard it yet?

5. Normally we don't notice the difference in times when each student hears the sound. Why?

6. Can you think of any situation where you have noticed a delay in the sound that you hear? Describe what is happening during one such experience.

B: The Speed of Sound

The speed of sound in air is given by the equation: $v = 331\ \text{m/s} + \left(0.59 \frac{m/s}{^oC}\right)T$, where T is the air temperature in degrees Celsius. The warmer it is, the greater the speed of sound. Sound can travel through all sorts of materials – gases (like air), liquids (like water) and solids (like the earth). The speed of sound also depends roughly on the density of the medium the sound waves travel through. A higher density medium generally produces a greater speed of sound.

1. What is the speed of sound in this room right now? You may need to make a simple measurement.

2. Describe a situation in which you have heard sounds waves travelling through
   (a) a liquid:

   (b) a solid:

3. What would happen in space? Imagine a foolish astronaut takes off his/her helmet and shouts!

SPH3U: The Propagation of Sound Homework

1. **Calculate and Explain.** A 30 cm violin string vibrates in its first harmonic and produces a concert A pitch of 440 Hz. The temperature of the room is 21^oC.
   (a)What is the speed of the wave in the violin string? What is the speed of the wave in the air?

   (b) Explain how you chose which information to use in the two calculations above.

2. **Calculate.** A deep, dark well has vertical sides and water at the bottom. You clap your hand and hear the sound wave from your clap return 0.42 s later. The air in the well is cool, with a temperature of 14^oC. How far down in the well is the water surface? (Use a solution sheet for this question)

3. **Calculate.** You are at a large outdoor concert, seated 300 m from the speaker system. It is a cool summer evening with a temperature of 18^oC. The concert is broadcast live via satellite (at the speed of light, 3.0×10^8 m/s). Consider a listener 5000 km away from the broadcast. Who hears the music first, you or the listener and by what time difference? (Use a solution sheet for this question)

Answers: (1) 264 m/s, 343 m/s, (2) 71.2 m, (3) 0.862 s

SPH3U: Resonance in Air Columns

Recorder: ______________________
Manager: ______________________
Speaker: ______________________
0 1 2 3 4 5

You may, or may not, be an accomplished bathroom shower singer. If you are, you are likely well acquainted with resonance in the shower. You might have noticed that while singing, if you find the right pitch, the loudness of your voice increases significantly and surprisingly. Something about the sound wave you created matched the volume of air you are in and resonance was the result!

A: Searching for Resonance in Air

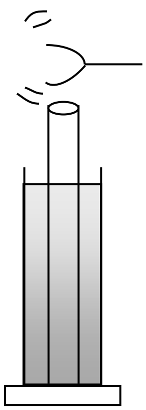
1. **Reminder.** What was the condition for resonance to occur?

2. **Speculate.** What characteristics determine the natural frequencies for a fixed volume of air like your shower?

3. **Reason.** You have a hollow tube with an adjustable length and a variety of tuning forks. You hold the vibrating fork near the opening of the tube, but hear nothing special (no resonance). Explain what characteristics of this situation you might change in order to produce resonance.

B: Standing Waves in an Air Column

You need a large graduated cylinder, a long plastic tube, a metre stick and a tuning fork (512 Hz are best). Fill the cylinder with water until about 5 cm from the top. **Have one group member in charge of making sure it does not tip over during the investigation.**



1. **Observe.** Strike and hold the tuning fork just above the tube. Slowly raise the tube from the bottom until you hear the first resonance – the sound will suddenly become louder. Keep striking the fork so it doesn't become too soft.

2. **Explain.** Why is this situation an example of resonance? What is the driving force? What part do you think is resonating?

3. **Predict.** Emmy says, "I think the plastic tube itself is resonating and producing the loud sound we hear." Marie says, "I think the air inside the tube is resonating and producing the loud sound we hear." Isaac says, "We need to test these two theories!" Your group will set up the air column so you hear the resonance and then have a group member hold the sides of the tube (don't do this yet!) Predict what will happen when the sides are held according to Emmy's theory and Marie's theory.

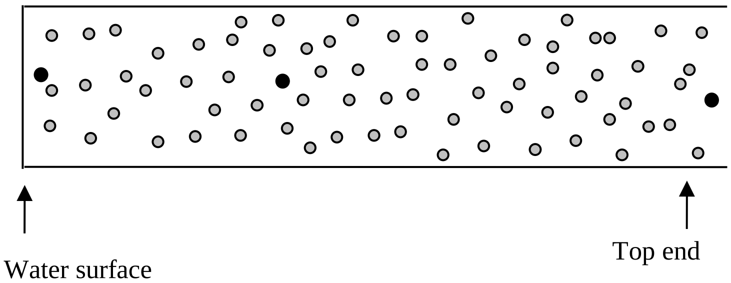
   Emmy:

   Marie:

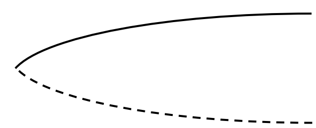
4. **Test and Evaluate.** Now you may conduct your test and evaluate the two hypotheses you created. Explain.

A standing wave forms when waves travel through a medium, reflect off the ends and interfere with waves travelling in the opposite direction (just like we studied with the springs). Sounds waves travel up and down the air column and reflect off the bottom end (the water surface) and the top end (the opening of the tube). The sound wave behaves differently at the two boundaries of this air column which we call the *boundary conditions*. One boundary condition is the *closed end* (our water surface). Here the air particles cannot be easily displaced because they are pushed up against the water surface. This creates a *displacement node* in the standing wave pattern. At the closed end, most of the wave's energy reflects back up the tube. The other boundary condition is the *open end* (the top of our tube). Here the air particles are easily displaced (no hard surface blocks them) and a *displacement anti-node* is created. At an open end, some of the wave's energy is reflected back into the tube (helping to create the standing wave) and some is transmitted into the open air around it, producing the sound wave that we hear.

5. **Represent.** The diagram to the right represents the air particles in your air column (tilted sideways) when a standing wave is present. Use arrows to show the **size and direction** of the displacement of the highlighted air particles. Label the boundary conditions at each end. Describe what direction the air particles move in and what direction the sounds waves move in.



6. **Represent.** To illustrate a standing wave, we can draw a standing wave diagram for the air column that shows the nodes and anti-nodes. This first example shows the fundamental mode (first harmonic) – the simplest standing wave pattern for your air column. Label the nodes and antinodes on this diagram.



7. **Explain.** We don't see a complete wavelength (or cycle) in this diagram. What fraction of the wavelength of this sound wave fits in your air column?

C: Finding Resonant Lengths

How does the length of an open-closed air column affect resonance?

1. **Explain.** Why is your air column called an *open-closed* air column?

2. **Observe.** Lift your tube up and down through a wide range of lengths. Does resonance occur at only one length? How many difference resonances (resonant lengths) do you notice?

3. **Reason.** When changing to another resonant length does the wavelength (or frequency) of the sound change? How can you tell?

4. **Reason.** As an example, think of a string fixed at both ends with a standing wave. The wavelength of the standing wave is not changing, but the length of the string is. Draw some sample standing wave diagrams to help illustrate how this is possible.

5. **Find a Pattern.** As the length of the medium gradually increases, what happens to the number of nodes and anti-nodes?

6. **Observe and Represent.** Make sure you have found the shortest air column that produces a resonance. This is called the *first resonant length*. Use a ruler to measure the length of air column. Draw the standing wave diagram for the particle displacements. How many wavelengths long is this pattern? Complete row 1 of the chart.

Resonant Length	L (cm)	L (λ)	Standing Wave Diagram
1			
2			

7. **Explain.** Based on your measurement and the diagram, explain how you can determine the wavelength of the sound wave.

8. **Observe.** Continue the experiment by looking for the *second resonant length*. This is the next length that will hold a standing wave pattern based on the frequency of the fork. Measure the length of this air and complete row 2 of the chart. Double check: if your diagrams are correct, the wavelengths in each should look the same.

9. **Summarize.** When an air column is increased in length from one resonant length to the next, what fraction of a wavelength is added to the standing wave pattern? (This is true for all standing wave patterns!)

D: Finding a Resonant Frequency

For this investigation you will use a large cardboard tube and a signal generator with a speaker set up at the front of the class. The cardboard tube has two open ends. To produce resonance this time, we won't change the length of the air column. Instead, we will change the frequency of the sound and find the frequencies that create a standing wave in the air column (like in the shower!)

An *open-open air column* has the boundary condition of two open ends. When resonance occurs and a standing wave is created in this air column, there is an antinode at each of the open ends.

1. **Represent.** The simplest standing wave pattern that can form in an open air column with a fixed length has one node in the centre and one antinode at each end. Draw this standing wave in the chart.

2. **Reason.** Measure the length of the tube. What fraction of a wavelength is in the air column? Complete the first row of the chart.

Harmonic	L (cm)	L = __λ	Standing Wave Diagram
First			
Second			

3. **Predict.** What is the frequency of the first harmonic? (You will need to make one more measurement to make this prediction.)

4. **Represent.** The second harmonic will have an additional node in the standing wave pattern. Complete the second row of the chart. Doubler check: are the lengths of your two standing wave diagrams the same?

5. **Reason.** Will the frequency of the second harmonic be higher or lower than the first? Explain.

6. **Predict.** What is the frequency of the second harmonic?

7. **Predict.** Quickly predict a few more harmonics. Try it!

8. **Observe.** Time to use the equipment! Adjust the frequency of the signal generator and watch the oscilloscope for the resonance. How can you tell when you have reached a resonance frequency?

9. **Test.** Determine the resonance frequencies from the signal generator. How do these compare with your two predictions?

10. **Predict.** The air column of most wind instruments is open-open. Take the length measurements for a particular note on the wind instrument your teacher has. Draw a standing wave diagram. Calculate the frequency of the first harmonic.

11. **Test.** Use the frequency analyzer to find the frequency of the instrument. How does this compare with your prediction?

SPH3U: Resonance in Air Columns Homework Name:

Complete these questions on your solution sheets. For **B: Physics Representations**, draw any wave diagram or helpful graphs of the waves. For **C: Word Representation**, describe the wave patterns or particle motion.

1. A deep, dark well with vertical sides and water at the bottom resonates at 7.00 Hz and at no lower frequency. (The air-filled portion of the well acts as a tube with one end closed and one open end.) The air in the well is cool, with a temperature of 14°C. How far down in the well is the water surface?

2. A clarinet behaves as an open-closed column of air with the open end at the bell and the closed end at the reed. Claudia blows very gently – just enough to play a low A with a frequency of 220 Hz. She then blows harder (overblows) using the same fingering and produces the next higher note (the next harmonic). What is the frequency of the higher note? (Hints: how does λ compare in the two situations? Use the universal wave equation to compare the frequencies.)

3. The air column of your steamy shower (26°C) is closed-closed since the sound will reflect off two solid walls at the front and back of the shower. The distance between the two walls is 1.50 m. Draw a standing wave diagram. What are the first two resonant frequencies?

Answers: (1) 12.1 m, (2) 660 Hz, (3) 115.4 Hz, 230 Hz