York Mills Collegiate Institute

Physics!

SPH4U
Course Handbook
Fall 2018

Student Name:

SPH4U: Course Syllabus

This syllabus contains a list of all classes, topics and homework in the Gr. 12 physics course. Questions listed in brackets are **optional**. We recommend using the option questions for test preparation or evidence of improvement.

Day	Topics	Homework

Introduction

1	Course Introduction, How to Answer a Question	Sign-up with course website Have parents sign course outline Handbook: *How to Answer a Question* Video: Top 10 Amazing Physics Videos
2	Groups Work	Handbook: *Improving Habits*
3	Measurement and Numbers	Handbook: *Measurement and Numbers*
4	Fermi Problems	Fermi Problem #1 on solution sheet
5	Short quiz on Introduction	Fermi #2 on solution sheet

Motion

1	Uniform Acceleration	Problems: pg. 27, #20, (21), 22 on solution sheet *Q#21 is optional!
2	Representations of Motion	Handbook: *Representations of Motion*
3	Cooperative Group Problem Solving	Problems: pg. 65 #22, pg. 67 #47, (pg. 30#3, 8)
4	CGPS	Problems: pg. 65 # 26, Fermi #3 (pg. 31#11)
5	CGPS, *continued* Special Events	Complete ball toss problem, Fermi #4 (pg. 170 #38)
6	The First Law in 2-D	Handbook: *2-D Motion*
7	Vector Components	Handbook: *Vectors and Components* (pg. 17#8)
8	Projectiles!	Handbook: *Projectiles!*
9	Projectile Problem Solving	Problems: pg.51 # 8, Fermi #5 (pg. 46#4, pg. 50 #4, pg. 170#41)
10	Projectile Problem Solving, *continued*	Problems: pg.51 #5, Fermi #6 (pg. 50#9&10, pg. 51#7, pg.66#36)
11	CGPS	Handbook: *Test Preparation* (on motion rubric page)
12	CGPS, *continued* Practice Test	Handbook: *Test Preparation*
13	Test	

Forces

1	Representing Forces	Hand Book: *Representing Forces* (pg. 73#5, pg. 92#2)
2	Forces in 2-D	Actually finish last class's homework! (pg. 73#7)
3	Understanding 2-D Forces	Handbook: *Understanding 2-D Forces Homework* (pg. 75#9ab, pg.92#7, pg.117#10)
4	Newton's 3rd Law	Handbook: *Magnets and the Third Law* Problem: pg. 244#1a (pg. 94#11, pg.96#11)
5	Weight and Acceleration	Problems: pg. 93#9, Fermi #7 (pg. 150#7)
6	CGPS	Problems: pg. 96 #9, Fermi #8
7	Frames of Reference	Problems: pg. 110 # 2, 3 (pg.168#24)
8	Strings and Composite Objects	Problems: pg. 94 #10, pg. 95-96 #3, 7
9	Tension and Pulleys	Problems: pg. 92 #5, pg. 95 #5 (pg. 117#8)
10	CGPS	Problems: pg. 96 #10
11	Friction!	Problems: pg. 101 #3, 7, pg. 168 #25, Fermi #9
12	Friction! *(continued)*	Problems: pg. 118 # 16, 25(a) (pg. 118#15)
13	Going in Circles	Problem: pg. 101 #5, Fermi #10 (pg. 133#2a)
14	Going in Circles, *continued* Radial Acceleration	Handbook: *Going in Circles*

Day	Topics	Homework
15	Radial Acceleration, *continued*	Problems: pg. 126 #8, 10, Fermi #11 (pg. 127#3, 5, 6)
16	Thinking About Circular Motion	Problems: pg. 133 #3, 138 #4, Fermi #12 (pg.133#4, 6, 7, 171#48)
17	CGPS	Problems: pg. 138 #6, Fermi #13 (pg. 150#10, 159#11, 161#26)
18	Universal Gravitation	Problems: pg. 143 #11, 12 (pg.143#10, 144#6, 160#17)
19	Orbits	Problems: pg. 147 #2, 6, use table pg. 776 (pg.171#46)
20	Orbits, *continued*	Handbook: *Test Preparation*
21	Test on Forces	

Energy and Momentum

1	"Oomph"	Handbook: "*Oomph*" parts C and D, pg. 243 #5 (243#4, 5, 8, 269#11)
2	The Idea of Conservation	Problems: pg. 237 #8, 248 #6, Fermi #14 (pg. 237#6, 7)
3	Types of Collisions	Problems: pg. 252 #12, 13, 14 (253#6)
4	Car Crash! Conservation of Momentum in 2-D	Handbook: *2-D Momentum Problem Solving* Problems: pg. 257 #3 (pg. 258#2, 259#4)
5	2-D Collisions	Problem: pg. 257 #5, 258 #3 (pg. 269#16)
6	CGPS	
7	Work and Kinetic Energy	Problems: pg. 183 #7, 186 #4, Fermi #15 (181#6, 186#5, 6)
8	Collisions Quiz, Gravitational Energy	Problems: pg. 197 #6, 201 #5, 227 #17 (161#27, 201#7, 227#20)
9	Energy Transfers	Problems: pg. 200 #13, 201 #8, 202#10 (227#18, 229#38, 311#48) Handbook: *Transfers of Energy*
10	The Ballistics Pendulum	Finish calculation in handbook, Fermi #16 (pg.270#19, 20, 271#32)
11	Spring Force and Energy	Problems: pg. 207 #5, 219#8 (206#3)
12	Spring Force and Energy, *continued*	Problems: pg. 211 #10, 13, Fermi #17 (pg. 227#22, 229#36, 307#13, 14)
13	CGPS	Problems: pg. 229 #38
14	Test	Handbook: *Test Preparation*

Special Relativity

1	Velocity and Frames of Reference	
2	Do You Have the Time?	Relativity Problems: #2-4, identify the **types** of intervals only
3	Space: The Final Frontier	Relativity Problems: #2-7, identify the **types** of intervals only
4	The Gamma Factor	Relativity Problems: full solutions #1, 2, 5, 6
5	Relativity Problem Solving, Visualizing Relativity	Relativity Problems: full solutions #3, 4, 7
6	Energy and Relativity	Relativity Problems: full solutions #8-10
7	Energy and Relativity	Relativity Problems: full solutions #11, 12

Day	Topics	Homework
	Electric and Magnetic Fields	
1	A New Kind of Interaction	
2	Relativity Quiz, A New Kind of Interaction (*continued)*	Handbook: *A New Kind of Interaction Homework*
3	The Strength of Electrostatic Interactions	Problems: pg. 335 #4a-d, 6 (331#2, 3)
4	Analyzing Electrical Forces	Problems: pg. 336 #6 (331#7, 334#4, 336#10)
5	Introducing … Electric Fields	Problem: pg. 334 #9 (find the magnitude only)
6	Electric Field Strength	Handbook: *Field Concept Homework* (pg. 343#2, 3, 378#12)
7	Fields with Multiple Sources	Problems: pg. 344#4 (378#14)
8	Moving Charges in a Uniform Field	Problem: pg. 371 #1a, 379 #27 (364#3, 379#15, 30)
9	CGPS	Problem: pg. 371 #2
10	CGPS, *continued* Magnetic Fields	Problem: pg. 380 #35
11	Magnetic Fields	
12	Magnetic Forces on Charges	**Please read**: pg. 395 (Sample problem 1b, c only) Problems: pg. 402 #1, 4, 396 #2-4
13	Electromagnetic Disturbances	
14	Understanding EM Waves	
15	Light and Polarization	Problems: pg. 498 # 4
16	Properties of 2-D Waves – diffraction, interference	Problems: pg. 454 #2, 3
17	Test	Handbook: *Test Preparation*

References

Many excellent resources were adapted to develop the physics lessons in this document. Many other resources inspired ideas throughout. 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.
- Heller, Pat and K. Heller. *Cooperative Group Problem Solving*: http://groups.physics.umn.edu/physed/Research/CGPS/GreenBook.html
- Van Heuvelen, Alan, and Eugenia Etkina. *The physics active learning guide*. Pearson/Addison-Wesley, 2006.
- Etkina, E. *Physics Union Mathematics*. http://pum.rutgers.edu/
- Knight, Randall. *Five easy lessons: Strategies for successful physics teaching*. Pearson (2003)
- Redish, Edward. *Teaching Physics with the Physics Suite*. Wiley (2003)
- Elby, A., et al. "Maryland Tutorials in Physics Sense-making." *DVD, funded by NSF DUE-0341447* (2007).

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.

SPH4U: Learning Log	Name:

One of the most important educational skills you can develop is how to monitor and track your own learning. Either at the end of class or at home, complete an entry in your learning log every day. It won't take long, just get in the habit of it.

Written Work: Use our marking scheme for daily class work (out of 5) to assess your written work. What mark do you think your work would receive if it was collected today?
Group Work: Use a marking scheme out of 5 to assess your contribution to the group's work and discussions. Remember that valuable contributions come in many forms: sharing ideas, asking questions, organizing the group, and more. If your teacher was observing your group for the full period, what mark do you think you would get?
Key Ideas / Difficulties: Record the physics ideas you learned well today. If you had difficulties with any physics ideas make a note so you will remember to get help with them. Also note whether you had any difficulties with the written work or group work, so can try to improve for the next class.
Homework: Check off the homework column once you complete the lesson's homework (also cross out the question numbers in your syllabus). If you have a problem with a question or get stuck, write down the question number.
Got it: Record the result of your effort to resolve any difficulties you had with the lesson or homework. For example, you might write: help from friend, saw teacher, figured it out, etc. If you had no difficulties or problems to take care of, check off this column indicating that you feel very confident that you understand the material of that lesson.

As your log fills up, get new pages from the course website or in class. It is your responsibility to keep you log up to date and have it ready for random checks in class, just like any homework.

Date	Lesson	Written Work	Group Work	Key Ideas / Difficulties	Home-work	Got it
Oct. 8	Motion #7	4	3	- Vector components: "part" of a vector in each direction - Draw component triangle to find components - No vector arrow for magnitudes - Don't understand how to find resultant vector yet	#3	Help from friend

SPH4U: Learning Log	**Name:**

One of the most important educational skills you can develop is how to monitor and track your own learning. It is your responsibility to keep you log up to date and have it ready for random checks in class, just like any homework.

Date	Lesson	Written Work	Group Work	Key Ideas / Difficulties	Home-work	Follow-up

SPH4U: Grade 12 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 45 minutes of physics homework per day on average. Homework problems will be randomly submitted for assessment and must be ready at the time of collection. 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 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 ~ 7 % each
T/I	14%	Daily work and regular quizzes ~ 2 % per group work check ~ 2 % per quiz
C	14%	Tests and Problem Solutions ~ 0.5 % per problem solutions or learning log ~ 2 % per test
A	14%	Challenges (CGPS) ~ 2 % per challenge
	30%	Exam

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 discuss with your teacher before you miss the class.

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.
- Contact 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 upon your return, 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

____
Student Name

SPH4U: Reassessing Your Physics Abilities

The Role of Tests and Quizzes in Learning Physics

Learning physics involves the development of two important abilities: an understanding of physics concepts and fluency with skills that apply the concepts. Our tests and quizzes are designed to measure your development of these abilities and the results of an evaluation often identify skills or understandings that can still be improved. We want to provide diligent students with the opportunity to improve: to have those abilities reassessed, and as a result, improve their mark in the course.

The Goal of Reassessments

A student who is eligible to be reassessed will write a new test or quiz of similar difficulty to the original one. The new assessment will be evaluated by your teacher and a new mark will be assigned that reflects the student's most recent achievements. The new mark will be a weighted average of the first and second evaluations, as determined by your teacher. This provides a substantial incentive to improve your abilities in physics.

The reassessment process is designed to encourage you to:

- focus on mastering new ideas by working thoughtfully every day in class
- refine your skills by completing daily homework exercises
- prepare thoroughly for tests and quizzes
- adopt a relaxed approach towards writing tests and quizzes
- learn as much as possible from the results of an evaluation and make an effort towards improving

The reassessment process is designed to discourage you from:

- slacking off in general and preparing poorly for the original test

Eligibility to Rewrite an Assessment

To have a reasonable chance for improvement, you must provide your teacher with evidence of your efforts to catch up on old work, keep up with new work, and improve. Your teacher will decide whether you are eligible to rewrite an assessment based on the *quality* of the evidence that you provide. We recommend that your evidence includes:

- ☐ **Old Unit Work:** The lessons in your handbook for the original unit are complete, including any lessons that might have been missed.
- ☐ **Past Homework:** No more than one (1) incomplete/zero on a homework check for the current unit. More than that will likely render you ineligible for a rewrite.
- ☐ **Record of Efforts:** The improvement log of the test is complete. This is a record of your efforts to improve your skills. We recommend working over a number of days and employing a variety of strategies (e.g.: extra help with your teacher, test correction, lesson review, practice problems, work with tutor)
- ☐ **Learning from Past Assessment:** Your test improvement page has been thoughtfully completed and represents very high quality work.
- ☐ **Practicing for Improvement:** You have completed new practice (such as problems on the full solution sheets) – check with your teacher for any suggested problems. The quality of the practice work must be very high (matching your goals for improvement) and clearly show the improvements you have made.
- ☐ **Current work:** All lessons and homework for the current unit are complete.

SPH4U Homework: How to Answer a Question Name:

Sign up with the course website and follow the *Course Introduction and Kinematics Lessons* link. For day 1, click on the link to: *Top 10 Amazing Physics Videos*. Explore the videos and select one to focus on when you answer the questions below. Remember the four criteria for high quality responses!

A: Watch Videos and Earn Marks! What a Deal!

1. **Record.** What is the title of your chosen video?

2. **Describe**. Describe what you observed in the video (what you saw or heard, but not any explanations).

3. **Reason**. Which unit from grade 11 physics does the video connect most closely to? (Kinematics, Forces, Energy, Sound and Waves, Electricity and Magnetism)

4. **Explain.** What was one interesting or surprising thing from the video?

B: Assess Your Responses

1. **Evaluate.** Use the questions below to help decide if your answers to the video questions are complete. Give each response a mark and use the 4Cs criteria to explain how you chose the mark.

Question	Follow-Up Question	Mark
A#2	Would your description be useful for someone who did **not** see the video? **Explain**.	
A#3	Did you cite evidence from the video and connect it to **specific** ideas from a grade 11 unit? **Explain**.	
A#4	Did you explain **why** the “thing” you mentioned was interesting **to you? Explain**.	

SPH4U: How to Answer a Question?

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

Sign up for your group roles today. Adjust your seating. Go through the introduction below together with your group. Feel free to take turns reading.

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.

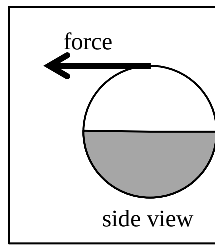
Criteria	**Description**	**Notation**
Correct	The physics is correctly stated. Conclusions follow logically from the stated evidence and refer to key definitions or laws. Technical details are all present and correct.	Incorrect sections are underlined and given an "__X__". Correct ideas are checked " √ "
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 earn marks based on the four 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	3	4	5
Responses are missing, 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, but 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 12 student wrote this?"

A: The Crazy Ball

Once your group has read through the criteria, come to the front of the class and use the "crazy" ball (two hemispheres with different densities). At this point your group is **not** allowed to talk.



1. **Observe**. Rest the ball on the table so its "equator" is horizontal. Push along the top of it to start it rolling in a "straight" line. Do this a few times until everyone has had a chance to observe its motion while it rolls. Then return to your seats and, **without any discussion**, record your observations.

2. **Reason.** What is the difference between an observation and explanation? Explain!

3. **Reason.** When your group is ready, take turns reading your observations to one another. Do not change what you have originally written. In order for a response to be correct and clear, it must use appropriate **physics** vocabulary correctly. What are the key physics terms that should be used to clearly describe how the ball was moving?

4. **Describe.** As a group, discuss a best way to describe your observations of how the ball moved. Record your revised observations here. *Bring your page up to the front of the class and follow the instructions for evaluating your response.*

***Compare your response to the model at the front of the class*

The *group discussion process* helps a group effectively answer a question. The process has four steps: (1) each person shares their initial ideas; (2) the group discusses the options; (3) the group decides on a response; and, (4) each person writes the response in their own words. You used this process to finalize your description of the ball's motion. This collaborative approach gives each group member the greatest chance of crafting a fantastic 5 out of 5 response for each question and improving your physics understanding.

5. **Reflect**. (*individually*) How comfortable did you feel when you read out your own description of the ball's motion? Why do you think you felt that way? What might help you improve?

The manager will help your group practice the *group discussion process* described above with each of the following questions. An important part of this is to make sure people take turns being the first one to share ideas. If the same person is always the first one to share, the others will get in to the habit of waiting for that person to speak. We all need to learn to worry less about being right, and to practice confidently sharing our ideas, whatever they might be. To effectively learn, you need to make clear to another person what you are **currently** thinking: only then can you begin to improve that thinking.

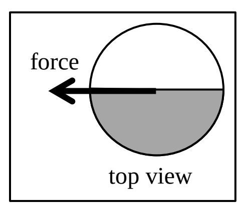
B: How to Learn and Earn

1. **Evaluate.** Another group (we won't mention any names!) offered this as their revised description:

   After pushing it, the ball kind of wobbled while it moved forwards in an almost straight line. Its motion was not very steddy and it's speed was changing.

   Use the 4 C's criteria and notation to mark up their response. Determine a mark and explain why in the space below. *Help the recorder write the mark and an explanation (max. 10 words) on a whiteboard*.

2. **Predict.** You will hold the ball on the table so its "equator" is vertical. You will then roll it forwards along the equator. (Call your teacher if you are not sure what this means.) How do you think it will move after it is released? (Note: groups do not need to agree on predictions, just share and discuss)



3. **Observe**. Go to the front of the class and try this out. Record your observations.

4. **Reflect.** (*individually)* What aspects of written work do you think you need to focus on the most in order to regularly earn 4's and 5's? How can you take advantage of the power of groups to help with this?

(start your learning log now)

SPH4U: Groups Work

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

Your group has a challenge: use the elastic attached to three strings (the "flux capacitor") to stack the cups into a pyramid. There are two rules: (1) only the elastic can touch the cups, and (2) you must hold the string at its **end**. Start!

A: Skills for the 21st Century

1. **Reflect.** What skills did your group make use of to accomplish (or partially accomplish!) this task?

2. **Explain.** Highlight one skill that you think was (or should have been!) the most important. Provide a short rationale. Record this on your group's whiteboard (ten words or less) and move on.

Here is a reminder of what we learned in grade 11 about how groups in physics work:

Roles

- **Recorder:** Write on the group whiteboard, help each group member carefully record the responses to each question, double check the group's physics notation, use of units, etc.
- **Manager**: Organizes and leads the group through the investigation and helps keep members focused on the same task.
- **Speaker**: Reads out the instructions and questions, speaks to the class or responds to the teacher on behalf of the group, asks clarifying questions so the speaker is always ready to present to the class.
- **Motivator:** If there is a fourth member, this person energizes the group, offers new ideas, encourages/praises the group

Set-Up

Sit in a triangle formation, facing one another. Whenever helpful, draw on a whiteboard to help the group discussions. Each group member is responsible for writing in their own words high quality responses for the investigations.

B: Refining the Group Discussion Process

There are many skills that we can improve to help make the *group discussion process* more effective.

Manager: *Ask your group to read over the group discussion process from yesterday's lesson.*

1. **Reason.** When we share physics ideas in our groups, we need to listen. What habits make a person a good listener?

2. **Reason.** We often listen to other people's ideas and think their ideas are wrong. While listening, should we: (a) tune them out or ignore the ideas, (b) try to figure out why the ideas are wrong, or (c) try to understand the person's thought process that led to the idea. Explain.

3. **Reason.** How we respond to someone with whom we disagree (or don't understand) has a *great* effect on the quality of the group's discussion and the feelings of our fellow group members.
   (a) Why is it unhelpful to say "No, you're wrong!" even to a close friend and especially to someone you don't know very well? Explain.

(b) When you disagree, why is it better to say, “Well, I think it might work like this….”

(c) Why is it even better to say something like, “I’m not sure. Could you explain how you came up with this …”

(d) How do these three ways of disagreeing relate to the three ways of thinking while listening (question B#2)

4. **Reason.** As part of the *group discussion process*, your group should decide on a final response. For most physics discussions, would it be best to make decisions by majority rules (2 out of 3 group members) or by consensus (everyone agrees). Explain how the type of decision-making affects the quality of the discussion and the feelings of the group members.

***Compare your response to the model at the front of the class*

5. **Reflect.** *(individually)* How do you usually respond to people you disagree with or don’t understand? What behaviours should you to remind yourself to use? How will you remember?

C: Teaching, The Super Skill

If you work in business or industry, you are pretty much guaranteed to be working in teams on projects that are too complex for any one person. New people will enter teams all the time and, whether you are a leader or team member, you will need to *teach* the new people many aspects of their job. In physics class, all group members have two important responsibilities: (1) always ask that question, right away when it arises; and (2) take the time to explain your ideas to others – to *teach*.

1. **Reason**. What is the benefit for the student who asks the question, and what is the benefit for the student who explains?

2. **Reason.** When something makes sense to us, we often explain it using a rapid-fire, “first this, then this, this and then ...” This is usually of no help to the other person. Why?

3. **Explain.** When we teach an idea it is helpful to know if the other person “gets it”. Why is it helpful to encourage the person to explain it back to you?

4. **Reason.** Think of the times when good teachers helped explain something to you. Very likely, they asked a lot of questions, combined with a bit of instruction, leading *you* to produce the answer. Why is this an effective technique?

(*start your learning log now*)

SPH4U Homework: Improving Habits Name:

Being a good student might seem very challenging. The **good news** is: things that are challenging will become easy after long-term, thoughtful practice. The **bad news** is: there are no short-cuts (*you* have to *do* the practice) and there are *many* long-cuts (bad habits that make learning needlessly harder or longer).

A: Habits and Goals

1. **Reflect.** Your teacher has very high expectations for you in grade 12. To help you reach these expectations, circle the responses that best describe your habits in grade 11. Be honest with yourself and be critical.

Student Habits	4	3	2	1
Practice: I complete my daily homework *before* the next class	Almost all the time	more than 75% of the time	about half the time	Less than half the time
Thoughtfulness: My written work in class *and* at home is carefully explained and shows all the steps (i.e. A, B, C, D, E solution steps)	thorough, a student could *easily* read and learn from my work (5/5)	good, but I might overlook some minor details (4/5)	basically correct, but not well explained, missing parts or steps (3/5)	rushed, incomplete, messy (2/5)
Initiative: When I have difficulty with an idea from class or the homework I get help	before the next lesson	within one or two lessons	by the end of the unit	rarely
Discussion: When working in groups, I share my ideas or ask for explanations	with almost every question	with a majority of questions	with just a few questions	rarely
Test Preparation: I prepare for tests by	reviewing and practicing thoughtfully over a few days	reviewing and practicing thoughtfully the night before	staying up late the night before	Only reading notes textbook, don't prepare

2. **Reflect.** In the chart above, the habits of good students are found in column 4. What are one or two reasons why some of your responses were in columns 1, 2, or 3?

3. **Reflect.** What is your goal for your grade 12 physics mark? Circle the appropriate range in the chart below. Ignore the second row for now.

Grade 12 Goal	50-59%	60-69%	70-79%	80-84%	85-89%	90-94%	95-99%
Habit Score	5-10	11-12	13-14	15-16	17-18	19	20

4. **Reflect.** Each column number in the "student habit" chart above represents a score. Add up your student habit score (maximum 20) and **circle** it in the goal chart above. This score is not exact or scientific, but will give you some useful perspective.

Think of your mark goal as a **habit goal** instead. Most students wrongly focus on marks and forget about their habits – this is a classic long-cut (a bad habit that makes learning harder). Once good habits are in place and are practiced thoughtfully for an extended period of time, the marks will come. Don't worry about marks: focus on habits and have a happier school life.

5. **Reason.** To feel successful in grade 12, your habit score needs to match your mark goal. Which habits do you need to improve to so your habit score corresponds to your mark goal?

Caution!

(1) Grade 12 comes with a greater workload and more responsibilities, making it challenging to maintain good habits from grade 11. Maintaining or continuing a high habit score is itself a worthy goal.

(2) If you know you need a certain mark for a particular university program, you need to build in a safety factor to your goal setting. If you **really** need 85% in physics, you should be setting your goals at the 90% level. There **will** be bumps along the way and days when you are not working at your best: you are only human. Having that safety factor helps prevent a few bad days from compromising your good goals.

B: Making Improvements

Reaching our goals depends on the many habits and behaviours that we use. Reaching new or more challenging goals often involves improving or making changes to our habits and behaviours, which can be hard for many reasons and requires more than good intentions. There are usually very predictable obstacles that prevent us from reaching our goals. Define your goals, identify the obstacles, create a plan that you can check to see if you are making progress.

1. **Reason.** Think about your habits and behaviours. Identify any challenges or obstacles that might prevent you from maintaining or improving your habits. Describe a plan that explains what concrete things you will do to prevent predictable obstacles from interfering with your improvement.

Habit	**Challenges / Obstacles**	**Plan**
Practice		
Thoughtfulness		
Initiative		
Discussion		
Test Preparation		

2. **Reason.** Having too many goals for improvement causes us to lose track of things. Which one habit do you think is the most important for you to improve or maintain? Why? (Highlight this goal in the chart above using colour!)

3. **Plan.** How will you keep track of your habits and behaviours so you can tell whether you are making progress? How will you remind yourself of what you need to do?

4. **Reason.** What will you do if obstacles knock you off your plan?

C: Some Suggestions

1. Did you identify **practice** as an important habit to improve? Consider this plan:

Practice. Your learning log is an important way to check on your daily practice and monitor how carefully you are doing your homework. Remind yourself to use the log and to return to this page every now and then to think about your plan.

2. Did you identify **test preparation** as your most important habit to improve? Consider this advice:

Test Preparation. Your thoughtfulness and discussions every day in class, and your practice every day at home are 90% of your test preparations. The final 10% is a bit of review and practice in the days leading up to the test itself. There is never any need to: cram the night before, stay up late, or neglect work for other classes. Do this and you will become a good student. What sounds challenging now will become easy if you follow this advice and stick to it.

SPH4U: Measurement and Numbers

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

Measurements form the backbone of all science. Any theory, no matter how slick, is only as good as the measurements that support it. Without careful measurements, science becomes guess work, hunches and superstition.

A: The Meter Stick

Our most basic scientific tool is the meter stick. But, do you know how to use it? Really? For this investigation you will need one meter stick

1. **Observe.** Each member of your group will independently (and secretly!) measure the height of your table. Don't share the results until everyone has made the measurement. Record everyone's measured values here.

The number we read from a measurement device is the *indicated value*. The *instrumental uncertainty* of a device is the smallest increment or change in a quantity that you can discern from the measuring device. The instrumental uncertainty may vary from person to person. If you think you can estimate a useful reading between the lines of a scale, do so. Always record a measurement as carefully as you can. Always record measurements using *measurement notation,* like this: "indicated value ± uncertainty". Some people refer to uncertainties as "errors", but this term is very problematic so we will never use it.

2. **Reason.** What is the instrumental uncertainty of your measuring device? Your estimation of this uncertainty may be different from the others in your group, and that can be OK as long as you are using the device appropriately. Explain how you decided on your uncertainty.

3. **Reason.** Now think about the height measurements your group has made. How do they compare with one another? Would you say, roughly speaking, that there is a lot of *uncertainty* or little uncertainty in your group's measurements? Explain.

***Compare your response to the model at the front of the class*

The *true value* is the actual, ideal value for a quantity that we are trying to measure. The true value of a quantity is usually **never known:** in science this is simply not possible (welcome to science)! Through hard work and ingenuity, we try to get our measurements (our indicated values) closer to the true value, but there is always some *uncertainty* due to the challenges of the measurement process!

4. **Reason.** Some groups find differences of about 0.5 cm amongst their height measurements. What are some suggestions for a future group to reduce the differences in their height measurements? (This is the ingenuity we mentioned.)

B: The Stopwatch

Now we will examine another common measuring device. You will need one stop watch or your smartphone.

1. **Observe.** Measure the amount of time for the pencil to drop from a 1 m height. Write this reading as a number in **standard decimal notation** with units of seconds.

2. **Reason.** What is the instrumental uncertainty of the stopwatch? Explain.

3. **Observe.** Perform the pencil drop seven times and record your data below.

4. **Reason.** Examine the individual measurements in your data above. You probably notice quite a bit of variation in them. What might be responsible for the spread in these values?

Repeated measurements will usually produce a range or *distribution* of values due to small random differences in the experimental setup or measurements. The size or width of this distribution is a measure of the *random uncertainty* associated with some result. One technique to find the width of the distribution is the *standard deviation*, but we will not use this in grade 12 physics. Instead, we will define the *uncertainty* (σ) using a **very crude** estimation of the width of the distribution:

$$\sigma = (\text{high value} - \text{low value})/(\text{number of measurements})^{1/2}$$

Use the instrumental uncertainty to limit the number of digits in your random uncertainty result.

5. **Reason.** What is the random uncertainty in this set of measurements? Show your work and record the end result using the instrumental uncertainty to limit the number of significant digits.

When we present a calculated result based on our measurements, we typically report two numbers: the best value (m), and the largest of the two uncertainty values (random or instrumental) written as: $m \pm \sigma$. This expression represents a *distribution of values* centred at the value m with a width of σ on each side. We interpret this expression by saying, "m is our best attempt at the true value, but we wouldn't be surprised if the true value was as high as $m + \sigma$ or as low as $m - \sigma$."

6. **Reason.** Calculate your best value for the time of the pencil drop. Use the two uncertainties to write your result using measurement notation. *Record your result on a whiteboard*.

Guidelines for Writing Numbers	
Measured numbers	• use the instrumental uncertainty to determine the last significant digit, write using measurement notation
Calculated numbers or Numbers from problems	• for <u>final statements</u>, use three significant digits to avoid too much rounding error • use scientific notation **only** when it is convenient (for really small or really big) numbers • for <u>middle steps</u>, keep an extra (a fourth) digit as a *guard digit* to help reduce the amount of rounding error. • write "round" numbers in a simple way: 2. When you need to be clear, write 2.00 or 2.000
Estimated numbers	• estimations are always very rough results. Usually one significant digit is all that is needed.

7. **Calculate.** Make a calculation to predict the time for the pencil to drop (use the equation $\Delta y = v_1\Delta t + \frac{1}{2}a\Delta t^2$ and $a = 9.8$ m/s^2).

A fundamental process in science is to decide whether two results "agree" with one another. We will adopt a simplified decision rule for this. Two results *agree* with one another if one lies within the uncertainty distribution of the other, or if their distributions overlap. In more advanced studies, you will greatly refine and strengthen this crude rule.

8. **Evaluate.** Does this calculated value agree with your measured result? Explain.

SPH4U Homework: Measurement and Numbers Name:

A: The Pebble Drop

It is sunset. You and a friend walk on to a bridge that passes over a river. After gazing off into the distance and into each other's eyes you both arrive at the same question: How high are we above the water? Luckily you have your smartphone with a timer app. Your friend finds a few rocks which he releases ($v_1 = 0$). You time the fall until you see them splash in the water below. Your data is shown below.

1.73 s	1.79 s	1.82 s	1.69 s	1.81 s	1.77 s	1.74 s

1. **Calculate**. Based on your measurements, find the best value for the time for the rock to fall. Express your result in the form $m \pm \sigma$ with an appropriate number of digits. Show your work.

2. **Calculate.** Use your time result to calculate the distance the rocks fell (use $\Delta y = v_1\Delta t + ½a\Delta t^2$). Your result from the calculation should use one or two guard digits. When write your final statement, use three significant digits.

D: Mathematical Representation

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

The time value you used in the calculation has an uncertainty, so we expect the distance result to also have an uncertainty. There are sophisticated techniques to find this uncertainty, but we will not use these in grade 12 physics. We will use the *weakest link rule:* determine which measured quantity has the greatest *percent uncertainty* (uncertainty/best value), assume the final result has the same percent uncertainty and calculate σ for your final result. Since this is a very rough rule, write σ with only one significant digit. Use σ to limit the number of significant digits in your final result. For example: suppose Δt = 1.54 s ± 0.11 s, which gives Δy = 11.62 m. % uncertainty = 0.11/1.54 = 7.14%, σ = 0.8 m, so the final result is: Δy = 11.6 m ± 0.8 m

3. **Evaluate.** What was the percent uncertainty in your time measurement? Use this as the percent uncertainty for your calculated result. Calculate the uncertainty of the result in metres. Write your final prediction with that uncertainty.

4. **Evaluate**. You look-up the height of the bridge on a website and find a value of 15.1 m. Does your calculated result agree with this value? Explain.

SPH4U Homework: Fermi Problems

When you solve a Fermi problem, be sure to define your key ideas with symbols and justify your estimations of them in Part A of the solution process. Complete parts B, C, D and E as usual. **Do not do any research for these problems!**

1. A stuntwoman falls from a tall building and lands in a giant airbag. Estimate the quantities you will need to **calculate** her acceleration while in contact with the airbag using a BIG 5.

2. A hockey stick collides with a puck during a powerful shot from the blue line. Carefully estimate the quantities you will need in order to **calculate** the acceleration of the puck while in contact with the stick using a BIG 5.

3. You are walking down the hallway and you realize you forgot your physics binder in your locker. You suddenly turn around to get it before you are late for class. What is your acceleration while you turn around? Carefully estimate the quantities you will need in order to **calculate** your acceleration using a BIG 5.

4. What acceleration does your body experience during a sudden stop in a car in a local parking lot? Estimate the quantities you will need in order to **calculate** your acceleration using a BIG 5.

5. You throw a ball horizontally. How far can you throw it?

6. After a successful semester of Gr. 12 physics you decide to try a career as a stunt person. For practice, you drive your motorbike to a parking lot where there is a bus parked. You set up a ramp that makes an angle of 40^o with the ground. Your goal is to jump over the bus! What is the minimum speed in km/h you should use?

7. What is the size of the force the ground exerts upon you when you push off to jump up high in the air? Use kinematic estimations to help determine your answer.

8. You take a ride in an elevator and travel upwards to the top floor of a building. As the elevator slows down you notice that you feel lighter. Estimate the quantities necessary to calculate your acceleration and then calculate your apparent weight while the elevator is slowing down.

9. A car screeches to a halt at a traffic light on York Mills Ave. Estimate the **kinematic** quantities you will need in order to calculate μ.

10. I saw the funniest thing one day in the school parking lot. I was arriving at school in the morning and someone (surely not a teacher) got into their car, started to drive away, and they forgot a box of Timbits on the roof of their car! What is the maximum acceleration possible for the car such that the Timbits don't slide off the roof? Estimate the quantities necessary (including the coefficient of static friction) to calculate the acceleration.

11. A car turns the corner from Bayview onto York Mills. Estimate quantities related to the motion and characteristics of the car that allow you to **calculate** the acceleration. What is the size of the force responsible for turning the car?

12. You push your little cousin on a swing until she is travelling quite high. How heavy does she feel (apparent weight) at the lowest point in the swinging motion? Estimate the quantities relating to her motion and **calculate** the forces.

13. I was with my daughter at the park one day, pushing her on the swings. I began to wonder: How fast would she need to be going at the top of her trip in order to go all the way upside-down (all the way around?)

14. What is the average force a baseball bat exerts on a ball? Estimate the kinematic quantities involved and use impulse and momentum to calculate the force.

15. A long-jumper lands in a sand-pit. What is the average stopping force the jumper experiences? Estimate the basic quantities involved and use the energy techniques to answer this question.

16. When I see a traffic light turn red I will sometimes just let the car glide to a stop instead of using my brakes. Estimate the quantities involved and make a calculation **using energy techniques** to find the size of the force of friction (the internal friction of the car's mechanical systems) that brings the car to rest.

17. When you sit down on a comfy couch, the cushion compresses. Estimate the quantities that allow you to calculate the spring constant of the cushion.

Warning! Fermi problems can have a fairly wide range of acceptable answers. An answer is usually good if it has the same order of magnitude (exponent) as the answers below. An answer might still be OK if the exponent is off by one.

Answers: (1) $1x10^2$ m/s^2, (2) $3x10^2$ m/s^2, (3) 2 m/s^2, (4) 6 m/s^2, (5) 10 m, (6) 20 m/s or 50 km/h, (7) $2x10^3$ N, (8) 2 m/s^2 and 80% your normal weight, (9) 1.4, (10) 5 m/s^2, (11) 5 m/s^2 and $5x10^3$ N, (12) 1.4 times normal, or 300 N, (13) 6 m/s, (14) $2x10^2$ N, (15) $2x10^3$ N, (16) $7x10^3$ N, (17) $6x10^3$ N/m

SPH4U: Fermi Problems

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

Enrico Fermi is a legend in the world of physics. He developed a remarkable ability to find rough but reliable answers to complex problems using simple reasoning and skillful estimations. We want to be like Fermi and solve "Fermi Problems"!

A: Feeling Hungry?

Here is your first Fermi problem: What mass of food do Torontonians eat in one year?

1. **Reason.** Imagine you had a truly smartphone that would allow you to look up the information you need to solve this problem. What information would be helpful to know for your solution? Record these on your whiteboard. You will share these with the class.

2. **Record.** We will call these pieces of information our *key ideas* for the Fermi problem solution. Record them here.

In Fermi problems, we don't usually know the values for our key ideas so we will need to estimate them. Because of this, use just **one significant digit** to record these values! Use scientific notation whenever it is helpful. You should be able to do all the math without a calculator! When you write the values for the key ideas, assign a variable to each.

3. **Reason.** One key idea is the number of days per year. A sample is shown below of **how you should write this**. Write the value for this key idea using one digit in scientific notation.

   Number of days per year: d = days/year (common knowledge)

Every number you use in a Fermi problem needs to be justified or explained. If a number is well known, indicate it as *common knowledge*. If it is not, you need to explain how you estimate it. The starting point for all estimations should be some number that you do know. You work from that number to get the value of your key idea.

4. **Reason.** Another key idea is the mass of food eaten by one person each day. You have seen many numbers associated with the food you eat. Use this to start your estimation. Explain your estimation using words or simple calculations.

   Mass of food per person per day: m =

   Population of Toronto: p =

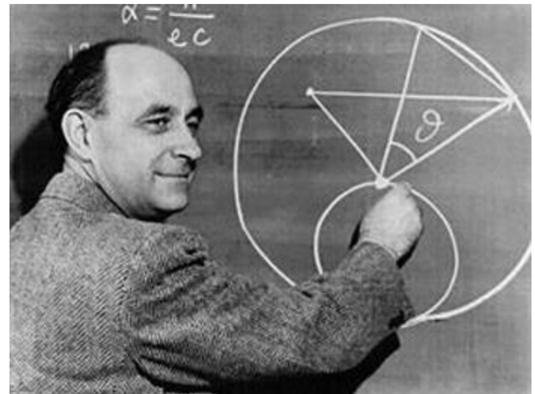
5. **Calculate**. Create an equation using symbols that will give a solution to the problem. Substitute the values (including units!) into the equation. State a final answer with one digit in scientific notation. Record your final statement on a whiteboard.

   Total mass: $m_t = m \cdot p \cdot d$

****Compare your response to the model at the front of the class***

B: More Fermi!

1. How many litres of water are used for drinking purposes each year in Canada?



Fermi estimating the size of his bald spot.

A: Pictorial Representation

Define key ideas with symbols, explain/justify estimations, label unknowns

D: Mathematical Representation

Complete equations, substitutions with units, final statement

2. A car travels on the highway and collides with the concrete pillar of an overpass. What is the acceleration of the passenger (buckled in) during the collision? Estimate the quantities you will need in order to **calculate** the acceleration. Show your reasoning and justify any quantities you estimate.

A: Pictorial Representation

Sketch, coordinate system, label key ideas/unknowns with symbols, conversions, describe events, explain/justify estimations of key ideas

D: Mathematical Representation

Describe steps, complete equations, substitutions with units, final statement

Fermi about to press a button

SPH4U: Uniform Acceleration

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

A: Gotta Love a Physicist in Uniform (Acceleration)

1. **Reason.** Describe how you could use a stopwatch and a police radar gun to decide whether a car was moving with *uniform* (constant) acceleration.

2. **Explain.** Use the idea of "net force" to help explain the condition that is necessary for an object to accelerate uniformly.

3. A cart is on a frictionless incline. Consider the following series of events: (1) The cart is at rest and you begin to exert a steady force on the cart up the incline. (2) The cart leaves contact with your hand as it rolls up the incline. (3) It reaches its highest point. (4) The cart returns to the bottom of the incline.
(a) **Reason.** Albert comments, "The cart is accelerating uniformly from moment (1) until moment (3)." Do you agree? Explain.

(b) **Reason.** Marie says, "The acceleration of the cart changes at moment (3). This makes sense because it changes direction." Do you agree? Explain.

***Compare your response to the model at the front of the class*

(c) **Predict.** Use a dotted line to sketch your prediction for a *v*-*t* graph for the cart's motion. Label events 1 through 4. As a class we will confirm this using the motion detector. Move on for now.

B: The BIG 5

The equations in the table to the right are affectionately known as the "BIG 5" equations of uniform acceleration. When an object is **accelerating uniformly**, the five kinematic quantities, Δd, v_i , v_f, a, and Δt, for that time interval are related by these equations.

For the BIG 5 to give reliable results, you must make sure that the object is accelerating uniformly during the entire time interval between the two events you choose – otherwise you need to choose new events!

	Δd	v_i	v_f	a	Δt
$v_f = v_i + a\Delta t$					
$\Delta d = v_i \Delta t + ½a\Delta t^2$					
$\Delta d = ½(v_i + v_f)\Delta t$					
$\Delta d = v_f \Delta t - ½a\Delta t^2$					
$v_f^2 = v_i^2 + 2a\Delta d$					

1. **Find a Pattern.** Place an "X" in the column of any quantity that is not found in each equation. Describe the pattern you observe in the chart.

Notation for Kinematics Variables: Remember that v_i and v_f are the instantaneous velocities at the initial and final moments of an interval of time. We will **always** use a numerical subscript corresponding to an event to help label different velocities and positions (for example v_2, v_3 for the velocities at moments 2 and 3). If you ever need to distinguish between two different intervals, you can write Δt_{12} compared with Δt_{23}, otherwise we just write Δt (similarly for Δd and a). For displacements in the *x*- or *y*-directions, write Δx or Δy instead of Δd.

2. You have some data for the cart problem we discussed in question A#3. At moment 3, $v_3 = 0$ m/s. During an interval, $a_{23} = -1.6$ m/s^2 and $\Delta x_{23} = 0.80$ m.
   (a) **Reason.** Is v_3 the initial or final velocity for this interval?

   (b) **Explain.** Describe how you can use the chart to help choose the best equation to find the time during this interval

   (c) **Calculate.** Complete the calculation to find the time interval.

D: Mathematical Representation

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

Did you check off each step for the mathematical representation?

Did you use the appropriate event subscripts in your symbols?

3. **Summarize.** (*as a class*) What is the magic saying for solving problems using the "BIG 5"?

C: The Solution to All Your Problems

The BIG 5 are equations that relate **vector** quantities. These equations take into account direction. A simple way to handle direction information is to use a sign convention and write down the BIG 5 using scalar notation. Each example shown to the right is correct, but the scalar version is often simpler and quicker to write down. **This will be our preferred notation**.

Vector notation - OK	Component notation - Best
$\Delta\vec{x}$ = 53 m [E]	$a = -0.59$ m/s^2 E → $+x$
$\vec{v}_1$ = 12.4 m/s[E]	$v_1 = 12.4$ m/s
$\vec{a}$ = 0.59 m/s^2 [W]	$\Delta x = 53$ m
Δt = ?	Δt = ?
$\Delta\vec{x} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$	$\Delta x = v_1\Delta t + \frac{1}{2}a(\Delta t)^2$

When we work out solutions for our homework, and on tests and quizzes we will use a very careful solution process. The rationale is this: the more carefully we think about a single problem, the deeper we will understand it. We will learn more by doing a few problems very carefully than by doing many problems carelessly. This helps us to learn how to explain what is happening in a problem using many different techniques. On the next page you will find the solution sheet that we will use for all our problem solving. **You must use this process for your homework problem solving.**

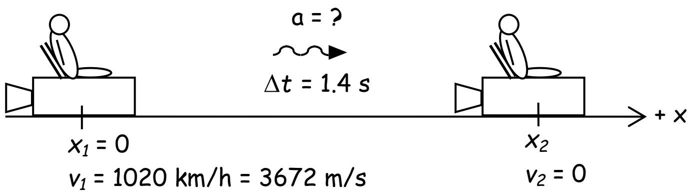
1. **Evaluate.** A world's land speed record was set by Colonel John P. Stapp when in March 1954 he rode a rocket propelled sled that moved along a track at 1020 km/h. The brakes were activated and the sled was brought to a stop in 1.4 s. What acceleration, in m/s^2 did he experience while stopping? A sample solution is provided **on the next page**. Its format is ideal, but there are minor errors in the math or physics. Circle all the errors, describe the error, and correct each one.

Motion Homework Sheet	**Problem:** Colonel Stapp!

A: Pictorial Representation

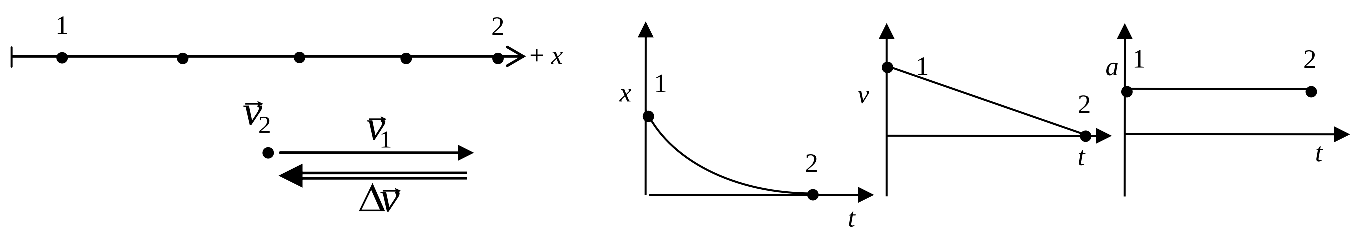
Sketch showing events, describe events, coordinate system, label givens & unknowns using symbols, conversions

Event 1 = he begins to slow down   Event 2 = he comes to a stop



B: Physics Representation

Motion diagram, motion graphs, velocity vectors, events



C: Word Representation

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

Colonel Stapp is initially moving rapidly in the positive direction and has a negative acceleration due to the sled's brakes. He slows down and comes to rest. I assume his acceleration is constant.

Since the sled stops very suddenly, I estimate an acceleration much bigger than freefall: a = 100 m/s^2

D: Mathematical Representation

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

Find his acceleration while slowing down. We know v_1, v_2 and Δt.

$v_2 = v_1 + a\,\Delta t.$

$\therefore a = v_1 / \Delta t$, since $v_2 = 0$

= (3672 m/s) / (1.4 s)

= 2622 m/s

I predict that he would slow down at a rate of 2600 m/s in the backwards direction.

E: Evaluation

Prediction has reasonable size, direction and units, why?

Since he was travelling very fast and slowed in a very small time interval, we expect his acceleration to be quite large.

His acceleration was negative while his velocity was positive which is correct for an object slowing down.

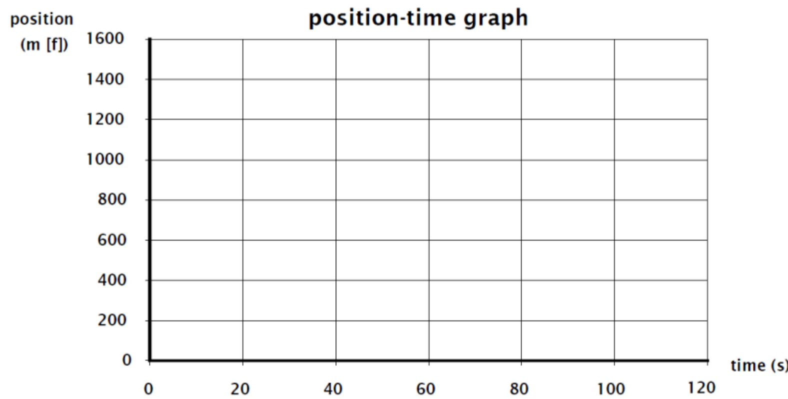
The units are m/s which are appropriate for acceleration.

Hint: Did you find seven unique errors?

SPH4U Homework: Representations of Motion   Name:

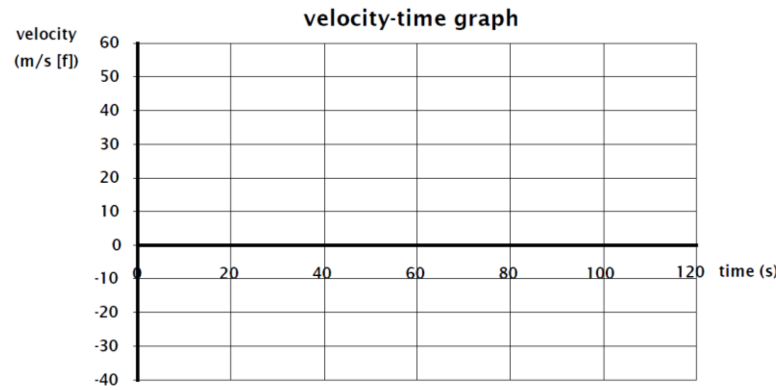
A car moves in a straight line starting from rest at the origin. You are given an acceleration graph.

The area between an acceleration-graph and the time axis gives the change in velocity of the object during that interval of time.

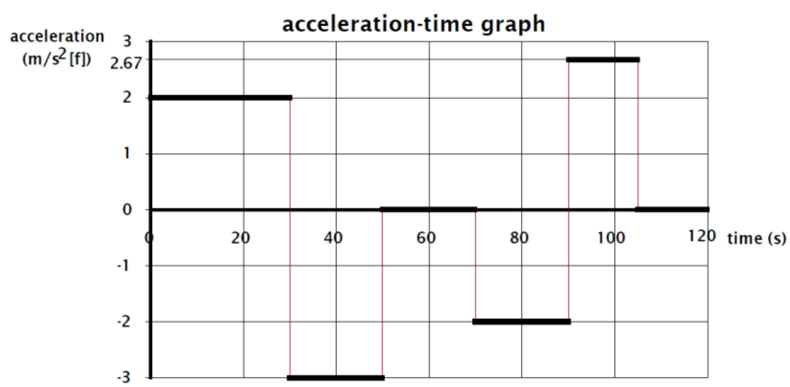


1. **Calculate.** Use a simple calculation to find the area under the acceleration graph during the first 30 s of the car's motion (shade in this area). Carefully show the units.

2. **Explain.** Describe the motion of the car during the first 30 s. Use specific values in your description.



3. **Represent.** Construct the velocity graph from 0 to 30 s. Explain how you choose to draw the line.



4. **Calculate and Explain.** Find the area under the velocity graph during the first 30 s. Describe what this area tells us about the motion of the car.

The **ruler trick** helps us to interpret curving position graphs. Think about the slope of tangents to the graph. Hold a ruler *tangent* to the position graph at three points: the beginning, middle and end of an interval. Decide if the object is speeding up or slowing down (the slope becomes larger or smaller). Is the starting or ending velocity fast, medium or slow?

5. **Represent and Interpret.** Draw the position graph from 0 to 30 s. Use the ruler trick to explain why your curve for the position graph is correct.

6. **Repeat!** Repeat this process to complete the velocity and position graphs.

SPH4U: Representations of Motion

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

A: Comparing Velocity Vectors

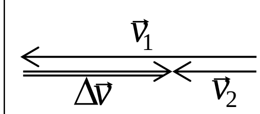
In grade 11 we have been drawing velocity vectors to provide another way of understanding motion. Now we will learn a special way to compare two velocity vectors and find the change in velocity.

1. **Explain.** How does the direction of the change in velocity compare with the direction of the acceleration?

2. **Explain.** A car is travelling west and slowing down. What is the direction of its acceleration? What is the direction of its change in velocity?

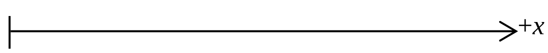
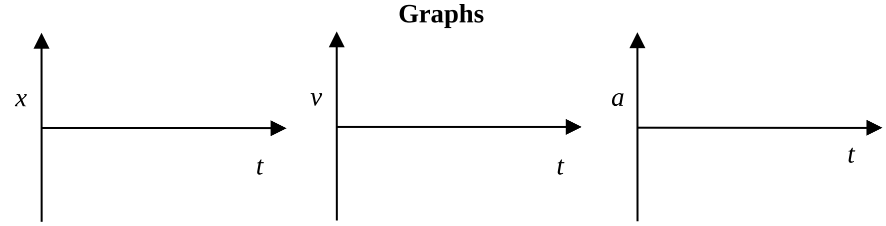
3. **Represent.** The car was initially moving at 10 m/s [W] and was later travelling at 3 m/s [W]. Draw each velocity vector and draw a vector representing your guess at the car's change in velocity.

The change in velocity can be found from the expression: $\Delta\vec{v} = \vec{v}_f - \vec{v}_i$. We can draw a vector diagram to represent this equation. In gr. 11 we learned that when we add vectors we draw them tip-to-tail. Here, the two vectors are subtracted. We represent this by drawing the vectors *tail-to-tail* (the tails of v_1 and v_2 are roughly at the same location). The change vector is a new vector going from the tip of the first to the tip of the second vector. This representation will be our **velocity-vector** diagram.



B: Representations of Motion

Your teacher has a cart with a fan attached to it on a dynamics track. Each chart below shows different cases of the cart moving along this track. We define the origin at the left end of the track and the positive direction to the right. Complete each chart using ideas that are reasonable for the motion of the cart along the track. If you are not sure how to complete a section of the chart, look for a chart that has a completed example.

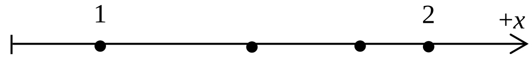
1	**Description of Motion**	**Motion Diagram**	**Velocity Vector Diagram**
	The cart is initially at rest and (1) begins to speed up, moving in the positive direction with a positive acceleration. At moment (2) the cart reaches the end of the track.	 **Sample Equation** $\Delta x = (0\text{ m/s})\Delta t + ½\,(0.50\text{ m/s}^2)\Delta t^2$	$\Delta v = v_2 - v_1$.
Real-Life Situation		**Graphs**	
			

***Compare your response to the model at the front of the class*

2

Description of Motion

Motion Diagram



Sample Equation

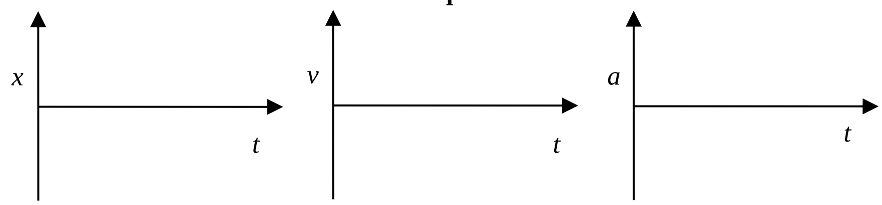
$\Delta x = (\quad\quad)\Delta t + \frac{1}{2}(\quad\quad)\Delta t^2$

Velocity Vector Diagram

Real-Life Situation

A car passes a police cruiser and (1) begins slowing down until (2) the proper speed limit is reached.

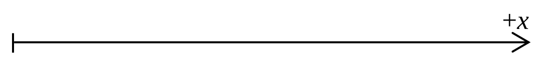
Graphs



3

Description of Motion

Motion Diagram



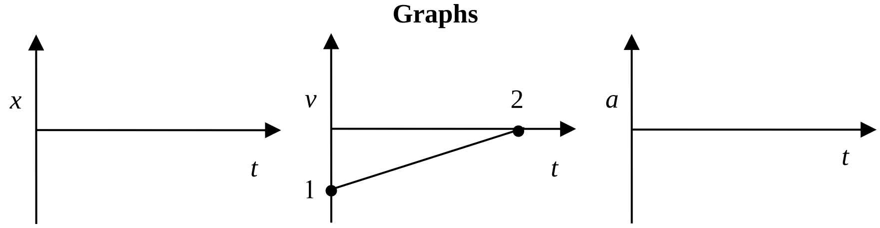
Sample Equation

$\Delta x = (\quad\quad)\Delta t + \frac{1}{2}(\quad\quad)\Delta t^2$

Velocity Vector Diagram

Real-Life Situation

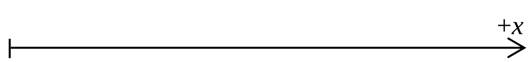
Graphs



4

Description of Motion

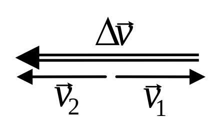
Motion Diagram



Sample Equation

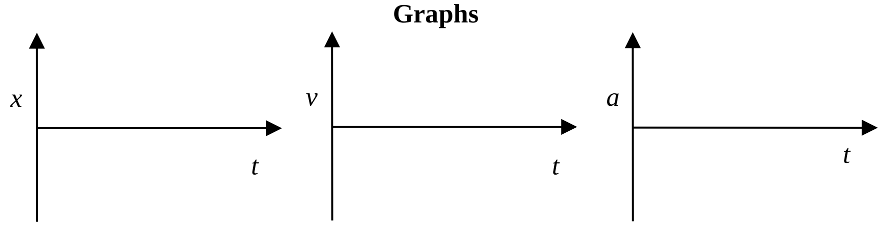
$\Delta x = (\quad\quad)\Delta t + \frac{1}{2}(\quad\quad)\Delta t^2$

Velocity Vector Diagram



Real-Life Situation

Graphs



SPH4U: The First Law in 2-D

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

We want to understand how forces and acceleration work when an object can move in two dimensions. Welcome to a bigger world!

A: The Hoverpuck

The hoverpuck creates a cushion of air that lifts it above the ground, so friction between the puck and the ground is very small. Imagine you give the puck a gentle push along the level ground and release it with a velocity $\vec{v}_1$ in the +*x*-direction.

1. **Predict.** Describe the motion of the puck **after** it leaves your hand.

2. **Test.** (*as a class*) Describe the motion of the puck along the level ground after it is released. Does this agree with your prediction?

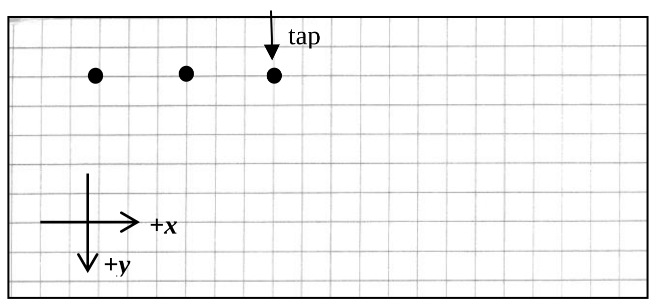
3. **Represent.** Draw three dots representing the position of the puck after equal intervals of time (much like our motion diagrams) in the grid above. Explain how you chose the spacing between the dots of your diagram.

4. **Reason.** Marie says, "The force from your push is carried by the puck as it travels along the floor. That's why it keeps moving forwards after your push." Do you agree or disagree with Marie? Explain.

B: One Tap

Now imagine you release the puck and then your friend gives it one short 'tap' in the +*y*-direction.

1. **Predict.** Describe the motion of the puck after the tap. What will the shape of its path be?



2. **Predict.** Describe how the overall **speed** of the object will change.

3. **Test**. (*as a class*) Describe the motion of the puck after the tap and describe the shape of its path. Does this agree with your prediction?

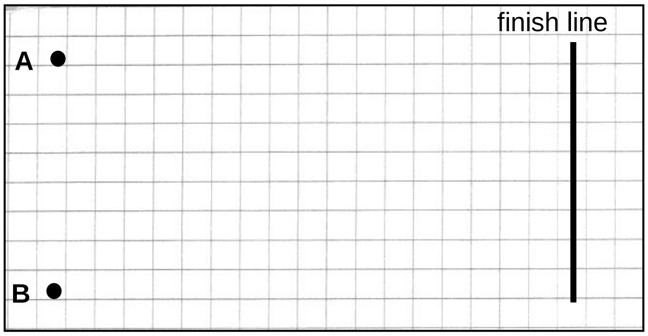
4. **Represent.** Draw three images of the puck three equal intervals of time after the tap.

5. **Explain.** Why does the puck gain speed in the *y*-direction?

6. **Speculate.** Did the puck gain or lose speed in the *x*-direction?

C: Off to the Races!

It is difficult to decide from our previous observations whether the speed in the *x*-direction changed after the tap. To find out, we will have a race between two pucks. Each puck starts with the same initial velocity in the +*x*-direction. Puck A travels on an incline tilted in the +*y*-direction. The puck B moves beside puck A along the level ground.



1. **Predict.** What is the shape of the path of puck A after it is released? Explain.

2. **Predict.** Which puck will reach the finish line first? Explain.

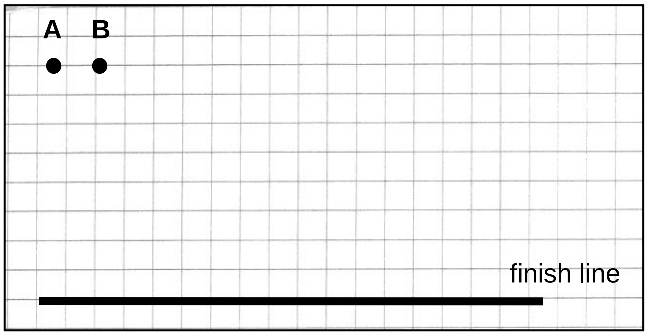
3. **Test.** (*as a class*) Describe the motion of Puck A after it is released. Does this agree with your prediction?

4. **Evaluate.** Did the velocity of Puck A in the *x*-direction change? Explain how you decided based on your observations of the race.

5. **Represent.** Draw three images of **each** puck after three equal intervals of time after they are released. Explain how you chose the *x*- and *y*-positions for the images of the pucks.

D: Rematch!

Consider another race. **Both** pucks are on the incline. Puck A starts from rest, while puck B has an initial velocity in the +*x*-direction.



1. **Predict.** Describe how you think puck A will move when it is released. Describe how you think puck B will move when it is released.

2. **Predict.** Which puck will reach the bottom of the incline first? Explain.

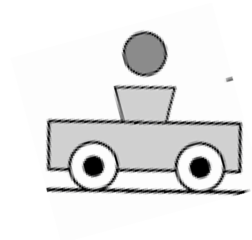
3. **Test. (***as a class*) Describe the motion of Puck A after it is released. Describe the motion of Puck B after it is released. Which won the race? Do these results agree with your predictions?

4. **Represent.** Draw three images of **each** puck after three equal intervals of time after they are released. Explain how you chose the *x*- and *y*-positions for the images of the pucks.

5. **Summary.** How does a force in one direction affect the motion of an object in the perpendicular direction?

SPH4U Homework: First Law in 2-D   Name:

A fun physics toy is a cart that has a built-in ball launcher. When the launcher is activated, it pushes **upwards** on the ball. The cart itself rolls with very little friction.



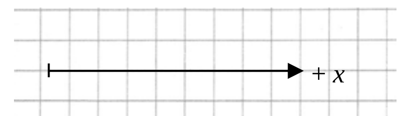
A: The Rolling Cart

You push the cart and release it. It rolls across a table.

1. **Reason.** In your model of the cart and its motion, what assumptions will you make?

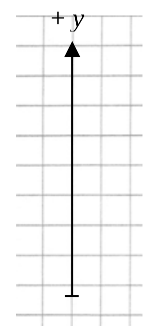
2. **Reason.** After your push, what is the state of force for the cart? What is the state of motion?

3. **Represent.** Draw a motion diagram for the cart as it glides across the table.



B: The Ball Launcher

A little later, you hold the cart stationary and trigger the ball launcher. The ball experiences a short, strong force upwards and then leaves contact with the launcher.



1. **Reason.** In your model of the ball and its motion after it is launched, what assumptions will you make?

2. **Reason.** After it is launched, what is the state of force for the ball? What is the state of motion?

3. **Represent.** Draw a motion diagram for the ball after it is launched until it returns to the cart.

C: All Together Now!

Now for the fun combination of these two: (1) you push and release the cart, (2) after a short while you launch the ball, (3) the ball returns back to its starting height. Launching the ball does not disturb the rolling of the cart.

1. **Reason.** Determine the state of motion and state of force for the cart and ball during interval 1-2.

	Interval 1-2	
	State of Motion	State of Force
Ball		
Cart		

2. **Reason.** Use Newton's 1st law in the *y*-direction to explain what happens to the vertical velocity of the ball during its launch.

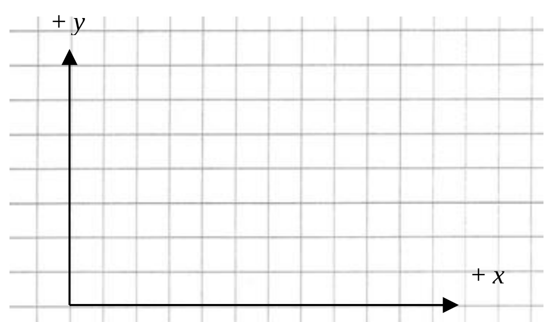
3. **Reason.** Use Newton's 1st law in the *x*-direction to explain what happens to the horizontal velocity of the ball during its launch.

	Interval 2-3	
	State of Motion	State of Force
Ball		
Cart		

4. **Reason.** Determine the state of motion and state of force for the cart and ball during interval 2-3.

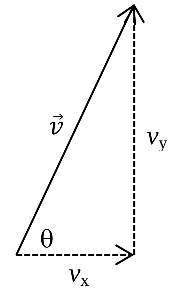
5. **Represent.** Draw a two-dimensional motion diagram for both the cart and the ball during both intervals of time. Label all events.

6. **Predict.** Compared with the cart, where will the ball land?

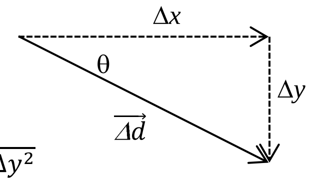


SPH4U: Motion Unit Rubrics

Component Triangles

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Triangle is constructed but contains many errors or a major error: • Vector's direction is misleading • The angle is not at the tail of the vector • The diagram is mislabeled	Component triangle contains no major errors, but might have a few minor errors.	• Components are drawn as arrows with dashed or coloured lines. • All three sides are labeled • The angle is shown at the **tail** of the vector. • Triangle clearly shows which component is larger • Vector's direction is reasonable • Components are labeled with the same symbol as the vector plus a subscript. (Displacement is the exception)	

Component Math

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Math is present but contains many errors or a major error: • Steps are missing • Component triangle missing • Problem with vector ideas	Work contains no major errors, but might have a few minor errors	• Component triangle included with math work • Appropriate physics symbols used • Substitutions have units • Both quantities on each side of the equals sign are written with vector or component notation (see pg.22) • Final 2-D vector written with vector notation	Δx = 3.1 m, Δy = -2.7 m  $\Delta d = \sqrt{\Delta x^2 + \Delta y^2}$ $= \sqrt{(3.1\ m)^2 + (-2.7\ m)^2}$ = 4.111 m $\theta = \tan^{-1}\left(\frac{\lvert\Delta y\rvert}{\lvert\Delta x\rvert}\right) = \tan^{-1}\left(\frac{\lvert -2.7\ m\rvert}{\lvert 3.1\ m\rvert}\right)$ $= 41.05^o$ $\therefore \Delta\vec{d}$ = 4.11 m [E 41.1^{o}S]

Vector Math

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
• Direction is missing	Work contains no major errors, but might have a few minor errors	• Only vector or square-bracket notation is used • Directions are included every time a vector quantity is written out	$\Delta\vec{d} = \vec{v}\Delta t$ = 6.7 m/s [E 41.1^{o}S] (0.6134 s) = 4.11 m [E 41.1^{o}S]

Projectile Solutions

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Solution contains many errors or a major error: • Components are not used	Solution contains no major errors, but might have a few minor errors.	• Part A: includes a component triangle • Part A: component calculations use sign convention correctly • Part A: list of horizontal and vertical information • Part B: motion diagram shows dot pattern for horizontal, vertical, and combined motions. • Vector notation ($\vec{v}$) is only used to label diagrams or with square bracket notation	

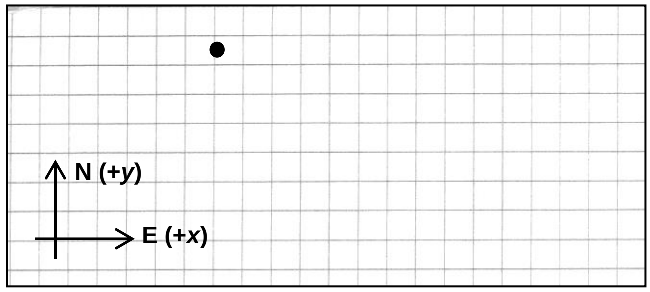
SPH4U: Vector Components

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

How do we analyze the two-dimensional motion of the puck from last class? We need to develop new vector techniques. Here we go!

A: Breaking Vectors and Finding Components

A video of yesterday's experiments allows us to find the velocity of our hoverpuck. After the hammer tap it had a velocity of $\vec{v}$ = 4.1 m/s [E 30° S] (starting east, measure 30° towards the south).



1. **Represent.** Draw this vector on the grid starting from the image of the puck and label it $\vec{v}$. The grid represents the *velocity-space* of the puck. This means that the lengths of vectors in this diagram represent the magnitude of an object's **velocity**. Use the scale of 1.0 cm = 1.0 m/s for the velocity-space.

All *vectors* have two parts: a number part (with units) called the *magnitude* and a direction part (the square bracket part or the +/- signs). To indicate the magnitude of a vector, we write $|\vec{v}|$ or just v for short. By definition, a magnitude is always positive, so $|\vec{v}|$ or v is just a positive number with units. Only use full *vector notation* when using square brackets for the direction, or to label a vector diagram. For example, $\vec{v}$ = 4.1 m/s [E 30° S] or $\vec{v}_1 \longrightarrow$

2. **Reason.** How fast is the puck moving after the hammer tap? What part of $\vec{v}$ tells us this? Write this using the appropriate symbols.

Drawing Component Triangles

(a) Draw the vector – this will become the hypotenuse of the component triangle.
(b) Create a right-angle triangle by drawing two smaller sides in the direction of the coordinate axes. Draw these sides with a different colour or dashed lines. Draw arrow heads for each side. Note that there are two possible triangles you could draw. Both are correct, but it is preferable to draw the one with the given angle **at the tail of the vector**.
(c) Label the angle inside the triangle **at the tail** of the original vector.
(d) Label the three sides of the triangle.

3. **Represent.** Construct the component triangle for the velocity vector of the puck after the hammer tap.

A *component triangle* shows the relationship between a vector (the hypotenuse) and its two *components* (the two smaller sides). We usually label the components by writing the original vector symbol (without an arrow!) and adding a subscript for the direction of the component: v_x and v_y. We will always write values of the components using *component notation* (using a sign convention to show the directions – this is what we have been doing throughout grade 11).

4. **Measure.** Use a ruler to measure the side lengths of your component triangle and use the scale to find the size of the components of $\vec{v}$. Be sure use the sign convention and include uncertainties!

   v_x = v_y =

5. **Interpret.** Explain what each component of the velocity vector tells us about the velocity of the puck.

6. **Calculate.** There are times when we want to find the components of a vector, but we don't want to use a ruler. In that case, we draw a component triangle and then use *trigonometry*. (Remember your SOH CAH TOA!) Use trig to find the two components of $\vec{v}$. Start by writing an expression only using symbols. Modify your expression by including a negative sign if the component should be negative.

***When done, compare your response to the model at the front of the class*

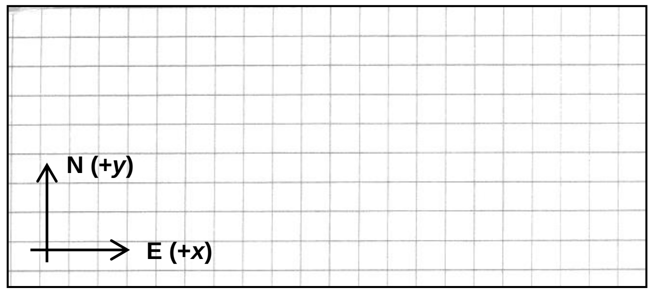
7. **Evaluate.** Do your measured components agree with your calculated components? Explain.

The displacement ($\Delta\vec{d}$) is the only vector that has different labels (Δx and Δy) for its two components.

8. **Calculate.** Suppose the puck travels for 1.3 s after the hammer tap, before hitting a wall. Use your calculated values for v_x and v_y to find Δx and Δy. Show your work carefully using the appropriate symbols.

B: Using Components to Find Vectors

Now we will draw a different kind of diagram. The grid now represents the *position-space* of the puck. This means that the lengths of vectors in this diagram represent the magnitude of an object's **displacement**. It no longer indicates anything about the object's speed.



1. **Represent.** Construct a component triangle starting with the two displacement components you have calculated. Use a scale or 1 cm = 1 m.

2. **Measure.** Use a ruler and protractor to measure the magnitude and direction of $\Delta\vec{d}$. Remember the uncertainties!

3. **Calculate.** Sometimes we want to find the magnitude of a vector without using a ruler. If we **only** know the length of the two sides of the component triangle, how can we find the magnitude of the vector? Write your equation using symbols first, and then calculate the magnitude.

4. **Calculate.** Sometimes we want to find the direction of a vector without using a protractor. If we **only** know the lengths of the two small sides of the component triangle, how can we find the angle **at the tail** of the vector? Write your equation using symbols first, and then calculate the magnitude.

5. **Evaluate.** How do your calculated values for the magnitude and angle compare with your measured values? Explain.

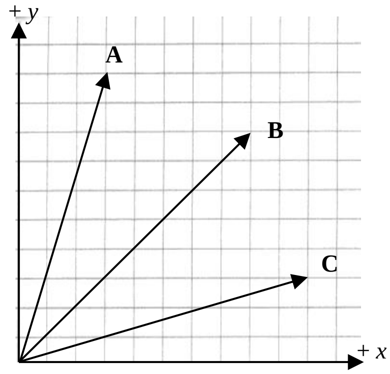
6. **Represent.** Write the displacement vector using full vector notation (using square brackets).

7. **Calculate.** We could have found this displacement in one step starting with $\vec{v}$! Write an equation using full vector notation that relates the displacement vector to the velocity vector. When you substitute the velocity value, be sure to write the direction using square brackets. Calculate the displacement.

In our physics work, we use component notation whenever we are describing physics along the direction of one coordinate axis. This is what we did all throughout grade 11. Most of our work in grade 12 will begin by breaking up vectors into their components. That allows us to analyze one coordinate direction at a time and use the simpler component notation. Sometimes at the end of our work, we put the components back together again to find the full vector.

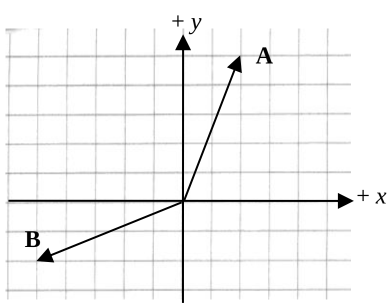
SPH4U Homework: Vectors and Components   Name:

1. **Reason.** Three vectors are drawn on the grid shown to the right. Rank the six components of these three vectors in order of increasing size. For example: $|A_y| > |B_x|$

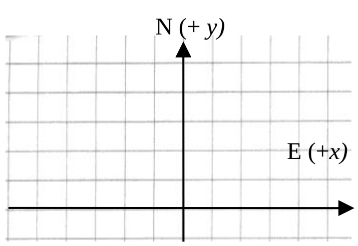


2. **Reason.** A vector makes a 30° angle with the *x*-axis. Which of its two components has the larger size? Explain.

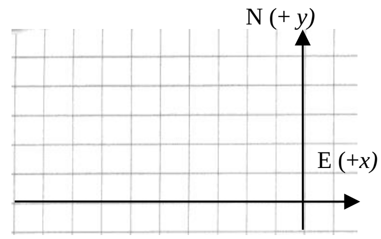
3. **Reason.** Two vectors are shown on the grid to the right. Rank the four components of these two vectors in increasing order according to **size**.



4. **Represent and Calculate.** A vector has the components: Δd_x = - 46 m and Δd_y = 30 m. Sketch a component triangle for the resultant vector (not a scale diagram!). **Calculate** the complete vector $\Delta\vec{d}$ including direction.



5. **Represent and Calculate.** A plane is travelling with a velocity of 340 km/h [N40° W]. Sketch a component triangle and calculate the components of this vector. (Don't draw a scale diagram!)



6. **Reason.** A plane travels at 600 km/h [E30°S] for 1.5 hours.
   (a) Draw a component triangle for the plane's velocity vector. Choose your sign convention. Find the components.

   (b) How far east does the plane travel?

   (c) How far south does the plane travel?

7. **Calculate**. While traveling to school, you traveled 3.4 km west and 2 km north. Your trip took 0.4 hours. What was your average velocity during this trip?

SPH4U: Test Preparation

A: Your Physics Abilities

We can break down your physics abilities into three parts:

(1) Core Ideas: These are the basic pieces of knowledge you need in order to do physics. Examples are definitions (e.g. displacement, net force, kinetic energy, voltage, resonance) and concepts (e.g. force causes acceleration, energy gets stored different ways). These ideas can usually be found in boxes in the handbook!

(2) Basic Skills: These are small things that you routinely do. (e.g. steps in solution process, motion diagrams, energy bar charts, 2^{nd} Law component equations, conversion ratios). Since you use these skills so often in so many different situations, the goal is to be able to perform these skills very quickly and accurately. These skills are often described in boxes in the handbook or have rubrics.

(3) Deeper Understanding: This is your ability to apply your physics ideas and skills to new situations. We use this ability to explain what is happening in a new situation or to make mathematical predictions. Many examples of this involve the combination of multiple core ideas and skills. These types of questions are often found at the end of an investigation or the end of a unit, and in our more challenging full-solution problems. This ability requires your core ideas and basic skills to be very solid.

B: Preparation Time

Learning takes time and preparing for a test is just another stage in learning. We have all heard people's heroic stories of staying up late and studying the night before. This strategy won't help in physics since we test your understanding of and ability to use physics ideas. These abilities take time to build and won't change much in one night.

1. **Plan.** Choose a block of time (1 or 1.5 h) during three different days before a test. Record this in the chart.

Studying Time and Date	Motion Test	Forces Test	Energy and Momentum Test	Fields Test
Day 1:				
Day 2:				
Day 3:				

Prepare during your planned time. Get a good night sleep the night before the test.

C: Test Preparation

When preparing for a test you should do three things:

(1) Review: Scan through each investigation or lesson for its core ideas, basic skills, and deeper understandings. Quickly re-read these to refresh your memory. Don't waste time writing summaries or study notes.

(2) Identify What to Practice: Look through your investigations, tests, quizzes, and homework. Identify any areas that need to improve. If you're not sure, find some examples from your handbook or homework to try. Try these under test conditions (no assistance, time limits). Don't waste time practicing things you are already good at.

(3) Improve. Find practice for your areas of weakness.
  (a) Core Ideas: Practice explaining the ideas to an imaginary friend. Use concrete examples.
  (b) Basic Skills: Find examples from throughout the unit (these are always very short questions or short parts of longer questions)
  (c) Deeper Understanding: Find good problems or interesting situations from the handbook or homework. Try these under test conditions.

SPH4U: Projectiles!

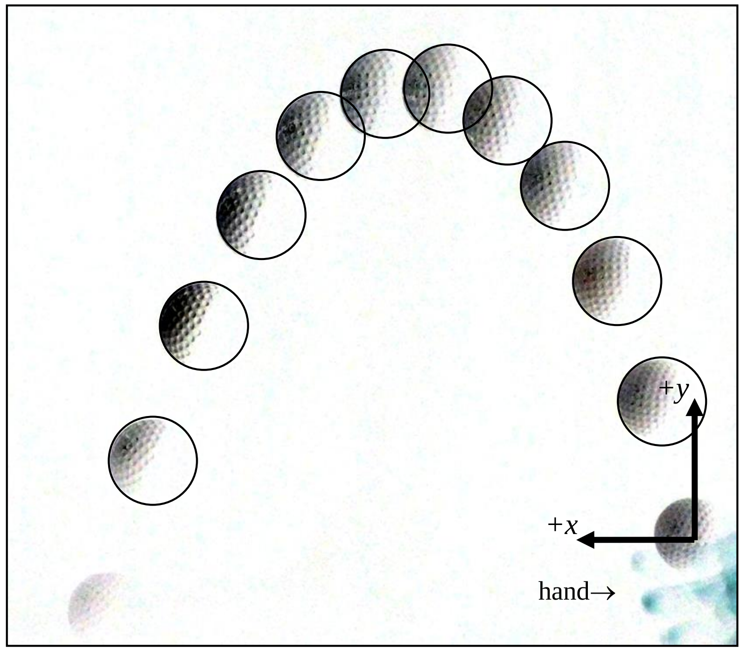
Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Now it's time to use our new skills to analyze the motion of a golf ball that was tossed through the air. Let's find out what is special about the motion of a projectile.

A: Tracking a Projectile

1. **Observe.** Choose a convenient reference point on the golf ball to help track its motion. Measure the *x*- and *y*-components of the **position** of the golf ball at each moment in time. The coordinate system for your measurements is drawn on the picture. The strobe light for the photo flashed at 10 Hz. Complete the chart below.

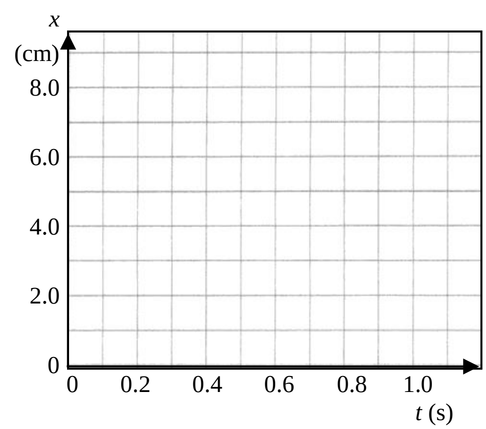
Image No.	*t*(s)	*x* (cm)	*y*(cm)
0	0	0	0
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			



B: Horizontal Motion

1. **Represent.** Plot a graph of *x* vs. *t*

2. **Interpret.** Describe the motion of the projectile in the *x*-direction. Explain how the data in the graph supports your interpretation.



When we analyze data graphically, we are looking for a relationship or pattern between the two related quantities. **Never** connect the dots on a graph and create a zig-zag pattern. Decide if the relationship fits a straight line or a smooth curve. No single data point is more important than any other (including 0,0!). A good line of best fit will be as close as possible to as many data points as possible.

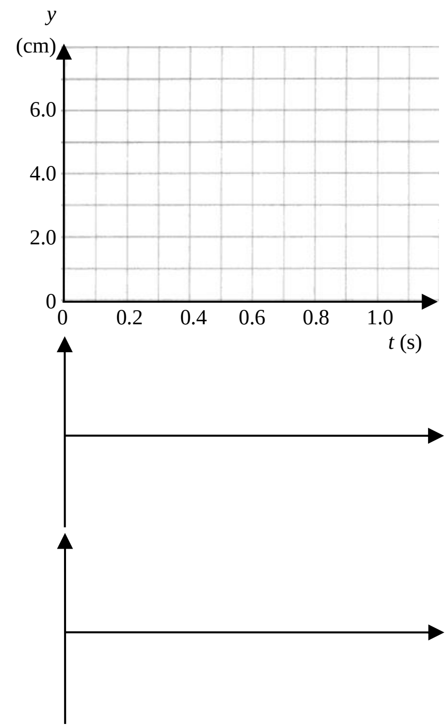
3. **Calculate and Interpret.** Find the slope of the position graph. State in words the meaning of this result.

4. **Reason.** Albert says**,** “This graph shows that there are no *significant* forces acting in the horizontal direction”. Do you agree or disagree? Explain. What can we conclude about the effects of air resistance?

*** call your teacher over ***

C: Vertical Motion

1. **Represent.** Plot a graph of y vs. t



2. **Reason.** Emmy says, “This graph shows evidence of a downwards acceleration.” Do you agree or disagree with Emmy? Explain.

3. **Represent.** Sketch a v_y-t and an a_y-t graph based on the y-t graph. Line up the graphs’ features with the y-t graph above. Label the regions in time when the ball is speeding up, slowing down and has a vertical speed of zero.

4. **Reason.** Marie says, “At its highest point the acceleration of the golf ball is zero since it’s turning around.” Isaac says, “No. At the top it’s still accelerating.” Who do you agree with? Explain.

D: Projectile Motion

1. **Summarize.** Use the observations you have developed to create a model of projectile motion. Your model should begin by explaining that we treat the object as a point particle. Describe the characteristics of the particle’s vertical and horizontal motions and mention any assumptions the model relies upon.

Projectile Motion:

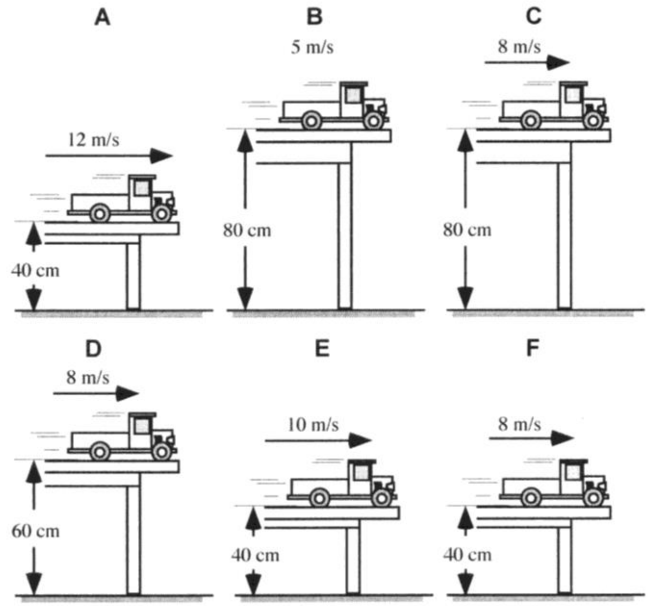
2. **Apply.** According to your model, will the golf ball ever be found falling straight down? Explain.

3. Predict. Two projectiles are launched with the same initial speeds but different angles. Marie launches hers with an angle of 60^o to the horizontal and Albert launches his at an angle of 30^o to the horizontal. According to your model, whose projectile will spend more time in the air? Explain. When you are ready, test this using your teacher’s computer simulation.

SPH4U Homework: Projectiles! Name:

The Orthogonality Principle: Forces acting in one direction have no effect on an object's motion in the perpendicular (orthogonal) direction.

You are using a toy truck to conduct some physics experiments that will explore the relationship between the truck's speed, the table's height and the time it takes the truck to fall and reach the floor. You plan on using the six situations shown in the diagram below.



1. **Reason.** Isaac has a hypothesis: "The truck's speed affects the time to fall" and his prediction is "The greater the speed of the truck, the more time it will take to fall." Which of the six situations could you use to best test his prediction? Explain.

2. **Evaluate.** Your results for the three different situations using the same height tables are 0.31 s, 0.27 s, 0.29 s each with an uncertainty of ±0.03 s. Do your results support or refute Isaac's prediction? Explain.

3. **Explain.** Isaac's hypothesis has been proven wrong. If he understood the orthogonality principle better he would have realized that his hypothesis didn't have a chance. Help explain to Isaac why his hypothesis was doomed!

4. **Reason.** Marie has a hypothesis: "The height of the table affects the time to fall" and she predicts "The greater the height, the greater the time to fall." Which of the six situations could you use to best test her prediction? Explain.

5. **Evaluate.** Your results from the three different situations using the same speed are 0.28 s, 0.35 s and 0.40 s each with an uncertainty of ±0.03 s. Do your results support or refute Marie's prediction? Explain.

6. **Explain.** Use the orthogonality principle to explain why Marie's hypothesis is reasonable.

7. **Reason.** Rank the six situations according to how much time the trucks spend in the air before hitting the ground, from smallest to largest. Explain your ranking.

SPH4U: Projectile Problem Solving

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

The key idea which allows us to solve projectile problems is the relationship between the horizontal and vertical motions. Since the vertical physics does not affect the horizontal physics, we can treat a single projectile problem as two related kinematics problems – one for each direction.

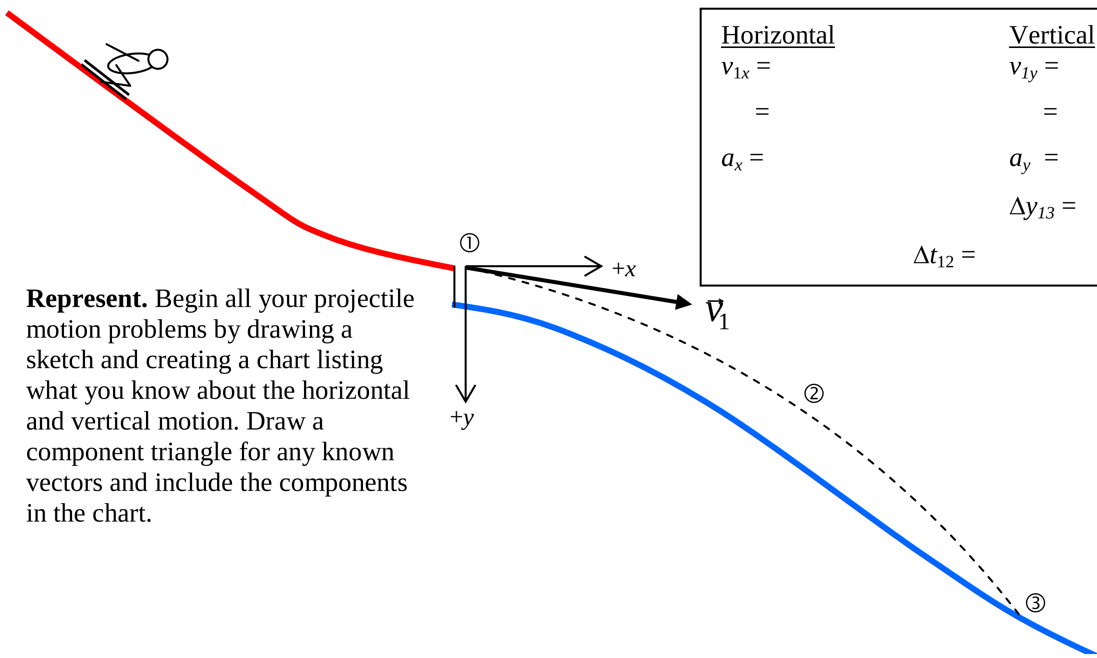
A convenient way to show the direction of the velocities used to describe projectile motion is to simply indicate the angle and use a sign convention with positive for above the horizontal and negative for below. For example: 12 m/s [32^o] or 150 km/h [-12^o]. Note that in component triangles, we always use positive angles.

The Ski Jump – One Giant Leap …

The ski jump is an exciting and death-defying event that turns human beings into projectiles! Let's study the physics of the craziest winter sport as featured at the Vancouver Winter Olympics in 2010. A typical ski jumper will be launched with a velocity of 26.1 m/s [-11.25^o]. What is hard to notice from TV and photos is that the launch angle is **below** the horizontal (downwards)! A jumper makes her leap and we note three events: (1) leaving the ramp, (2) part way down after 1.8 s, and (3) just before landing, 35.8 m below the starting position.

A: Pictorial Representation

Sketch, coordinate system, label givens & unknowns, conversions, ~~describe events~~, component triangle(s)



Horizontal	Vertical
v_{1x} =	v_{1y} =
=	=
a_x =	a_y =
	Δy_{13} =
Δt_{12} =	

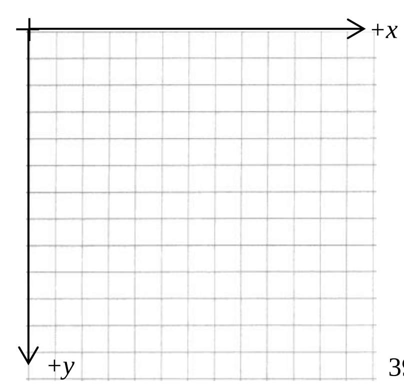
1. **Represent.** Begin all your projectile motion problems by drawing a sketch and creating a chart listing what you know about the horizontal and vertical motion. Draw a component triangle for any known vectors and include the components in the chart.

B: Physics Representation

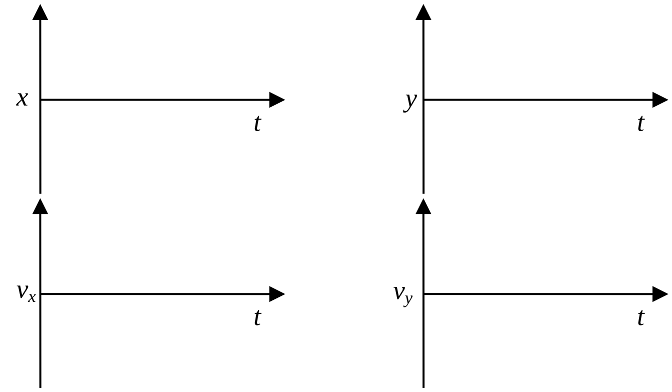
Motion diagram, motion graphs, velocity vectors, force diagram, events

For two-dimensional motion we will draw a special kind of motion diagram. Start by drawing a motion diagram along the *x*-axis for the motion in the *x*-direction.Next, do the same for the *y*-axis. Finally, use the two motion diagrams to help draw a third one using the grid which shows the complete, two-dimensional path of the object.

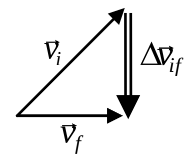
2. **Represent.** Complete the 2-D motion diagram for the ski jumper. Be sure to label events 1, 2 and 3. Don't worry about being too precise, as long as the correct ideas are shown. Describe how you chose to draw the dot patterns along the *x*- and *y*-axes.



3. **Represent.** Complete motion graphs for the *x*- and *y*-components of the ski jumper's motion.



A velocity vector diagram shows the relationship between a pair of velocity vectors and shows how the velocity has changed. This is summarized by the equation: $\Delta\vec{v}_{if} = \vec{v}_f - \vec{v}_i$. Draw the vectors v_f and v_i **tail-to-tail** in order to subtract them. The change in velocity, $\Delta\vec{v}_{if}$, points from the tip of v_i to the tip of v_f. When drawing your 2-D velocity vectors, make sure that both the lengths and directions seem right for the moments in time you are considering.



4. **Represent**. Draw the velocity vector diagram for events 1 and 2. Draw a force diagram for the ski jumper.

Vectors $\Delta\vec{v}_{12} = \vec{v}_2 - \vec{v}_1$
Force Diagram

5. **Reason.** How do the directions of Δv, a and F_{net} compare? Why?

6. **Represent.** Complete the word representation describing the physics below.

C: Word Representation

Describe motion (no numbers), explain why, assumptions, ~~estimated result (no calulations!)~~

7. **Solve.** Find her complete velocity vector (magnitude and direction) at moment 2. Complete the math representation below.

D: Mathematical Representation

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

***Compare your response to the model at the front of the class*

8. **Evaluate.** Imagine you erased all the math in part D above. Would your descriptions of the steps be good enough to help a struggling student work their way through this problem? If not, go back and improve them! Then complete part E, the evaluation, below.

E: Evaluation

Answer has reasonable size, direction and units? Why?

*** Call your teacher over to check your work. Then you are ready to check your results against the simulation***

9. **Solve.** How far has the skier travelled horizontally between moments 1and 3? Answer this in Part D below. **Note**: In this calculation you will encounter a quadratic! Don't panic! Substitute the quantities you know, leave out the units and then use the quadratic formula.

D: Mathematical Representation

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

10. **Reason.** Emmy says, "I was wondering about this. Imagine I toss a blob of playdoh which lands on the floor. When it hits the floor its final velocity is zero. Do you think I could use $v_2 = 0$ in my BIG 5 equation?" Can she? Explain.

The Great Jumper

Sondre Norheim (1825 – 1897) was a ski jumping champion and the designer of the modern ski used for ski jumping. The modern ski acts like a wing, providing the jumper with an upwards lift force. In gr. 12, we ignore all effects of the air and this upwards force. The story goes that Sondre wowed a group of spectators by jumping over a very tall rock. Let's explore the physics of this daredevil event. We will suppose that he launched from a ramp with a speed of 18.0 m/s at an angle of 28^o above the horizontal. The edge of the ramp was 1.5 m above the ground level. The tallest point of the rock was located 13.8 m horizontally from the edge of the ramp and was 5.0 m above the ground. The ground in this area is quite level. Complete the three parts of the solution below.

A: Pictorial Representation

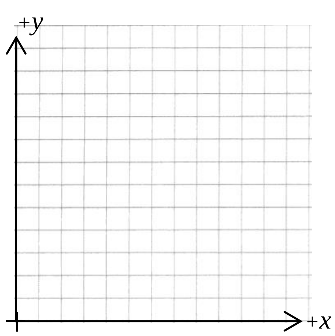
Sketch, coordinate system, label givens & unknowns, conversions, describe events, component triangle(s)

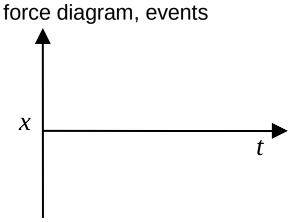
Horz __________ Vert __________

1. **Reason.** Our goal is to determine whether or not he will make it over the rock. What kinematics quantity would it be helpful to find (and compare with the given information) that would allow you to decide? Explain carefully.

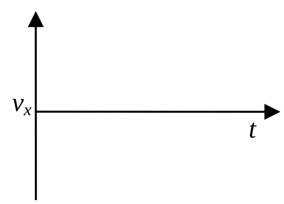
B: Physics Representation

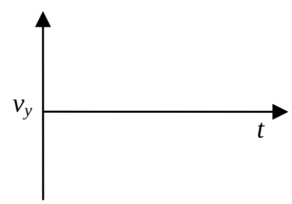
Motion diagram, motion graphs, velocity vectors, force diagram, events





Velocity Vector Diagram





Force Diagram

2. **Calculate.** Solve this problem in part D below.

D: Mathematical Representation

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

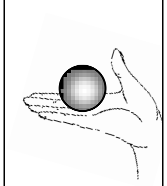
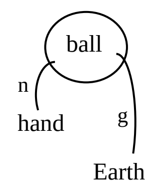
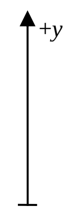
SPH4U: Representing Forces

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

Forces make the world go round! They are the real reason you get up in the morning. To help us understand forces we use a variety of tools which we will explore today.

An **interaction diagram** helps us to visualize the interactions between the system objects and the environment. Start by writing the name for each object involved in the interactions. Draw circle around the system objects to highlight them. Draw an interaction line connecting the names of each pair of objects in each interaction. Label these lines with a letter similar to the ones you use to label forces.

A: The Handy Ball

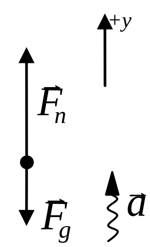
Sketch	Interaction Diagram	Motion Diagram
		

1. **Interpret.** What does the interaction diagram tell us about this situation?

2. **Represent**. The ball is moving downwards and is slowing down. Draw the motion diagram for the ball.

A **force diagram** uses our understanding of the interactions to construct a picture of the forces acting on a system. When you construct a force diagram:

- Identify the object or objects of interest – we will call these objects the **system**. Objects outside the system are parts of the **environment**.
- Represent the system as a point-particle where we imagine all its mass is compressed into a single point.
- Draw a vector arrow representing each force acting on the system associated with each interaction. The force vectors do not need to be drawn to scale, but should be drawn roughly according to their relative magnitudes.
- Include a separate wiggly acceleration vector when appropriate.
- Draw a coordinate system with a sign convention. In most cases, it is convenient to choose the direction of the acceleration as positive; otherwise choose the direction of the velocity as positive.

Force Diagram	Newton's 2nd Law
	$F_{net\,y} = ma_y$ $F_n - F_g = ma_y$

3. **Reason**. Examine the force diagram for the system. Do the lengths of the vectors correctly represent this situation? Explain.

The total effect of all the forces acting on the object is called the net force, F_{net}. To calculate the net force, we must add up all the force vectors found on the FD. To do this, we construct two component equations that represent the *x*- and *y*-components of Newton's second law. Make sure you do this even if the net force is zero. Always write the component equation for the 2nd law using **the force sign convention**.

The Force Sign Convention: In gr. 12 we will write component equations for forces (**no vector arrows**!). When we do, all force symbols, such as F_g, are magnitudes meaning they are *positive quantities*. Show the directions of the forces by using a sign convention and adding or subtracting the appropriate force symbol.

4. **Explain.** Examine the component equation for Newton's 2nd law in the box above. Explain what the implicit (hidden) positive sign in front of the F_n and the minus sign in front of the F_g tell us about the two forces.

5. **Reason.** Consider two similar situations where the ball is (1) at rest and (2) moving downwards and speeding up. Would an interaction diagram for either of these situations look different compared with the first one above?

6. **Represent and Explain.** Why are the accelerations different in these two cases compared with the first one? Draw the force diagram for each situation to help explain.

FD at rest	FD moving down

When a person is pushing on an object, we label that interaction and force "applied". We must keep in mind that **an applied force is really a normal force** (and in some circumstances a normal force plus a friction force). If you include an applied force on a force diagram, be careful you don't include the normal force from the same interaction! For clarity, we have only labelled normal forces in today's force diagrams.

7. **Predict.** When you place a heavy object in your hand, you feel pressure against your hand. Which interaction, gravity or normal do you think your hand responding to? Explain.

8. **Test and Evaluate.** Place a heavy mass (~1.0 kg) in the flat palm of your hand. Move the mass around just like the ball in the three situations described above. Does the sensation your hand experiences change? Use this observation to evaluate your prediction.

B: The Skydiver!

A skydiver is now falling at a constant speed because her parachute has deployed.

1. **Represent.** Complete the chart to the right for the system of the *skydiver and parachute*.

2. **Explain.** There is a tension interaction between the skydiver and the parachute. Should we include a force on the FD due to this interaction? Explain.

Interaction Diagram	Motion Diagram	Force Diagram	Newton's 2nd Law
	$+y$		

3. **Reason.** Emmy says, "Since the skydiver is moving downwards, the net force should be downwards." Marie says, "I think its zero." Who do you agree with? Explain.

The Air Resistance Rule: In Gr. 12 physics, we will always assume there is no force due to air resistance unless it is mentioned or the situation does not make sense without it.

C: The Trampoline

You are bouncing very high up and down on a trampoline. We will describe the force the trampoline exerts on you as an elastic force (F_e).

1. **Represent.** For each interval during your bounce, draw:
   - a motion diagram
   - a force diagram

(1-2) Traveling downwards and slowing down due to the trampoline	**(2-3) Travelling upwards and speeding up due to the trampoline**	**(3-4) Moving upwards after leaving contact with the trampoline**	**(4-5) Moving downwards before landing back on the trampoline**
+*y*	+*y*	+*y*	+*y*

2. **Reason.** Isaac says, "On the force diagram for moment 3 we should draw an upwards force due to the trampoline since he is still traveling upwards. We should make it smaller than gravity since that force is running out." Do you agree or disagree with Isaac? Use an interaction diagram to help explain.

ID

3. **Reason**. If there is no upwards force acting on you at moment 3, why do you continue moving upwards? Explain without using the word *inertia*.

The Force-Change Principle: All objects made of ordinary matter have the property of *inertia*. This property means that it takes time (an *interval* of time) in order for the velocity of any object to change. The time interval in some cases may be very small, but it is **never** zero. The amount of inertia is the object's *mass*. Inertia is **not a force**- it is a property of matter.

D: Book Learnin'

Isaac is pushing a heavy textbook towards Marie across the rough surface of a table. While Isaac is pushing, Marie helps to slow it down with her hand before it falls off the table.

When multiple forces point in the same direction, draw those forces tip-to-tail, just like you do when adding vectors in a vector diagram. That way we can easily see the total force in each direction.

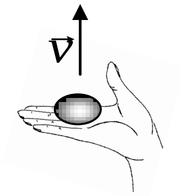
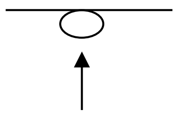
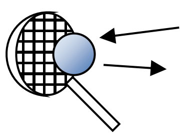
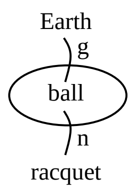
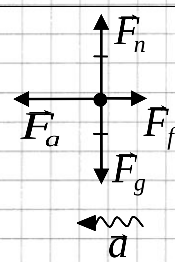
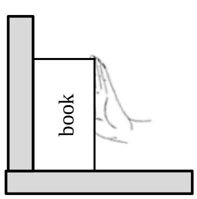
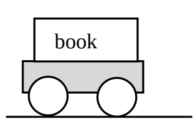
1. **Represent.** Complete the chart for the system of the book while the two of them are pushing on it.

2. **Explain.** How did you decide on the length of the force vectors in your force diagram?

Interaction Diagram	**Force Diagram**	**Newton's 2nd Law**
Motion Diagram +*x*		

SPH4U Homework: Representing Forces Name:

Complete the chart for each situation.

	Description	Sketch	Interaction Diagram	Force Diagram	Newton's 2nd Law
1	A tasty chocolate in your hand is moving upwards and is slowing down as it approaches your mouth. System = chocolate				
2	A ball was thrown straight upwards and hits the ceiling. System = ball				
3					$F_{net\ x} = ma_x$ $-F_f = ma_x$ $F_{net\ y} = ma_y$ $F_n - F_g = 0$
4	A tennis ball is struck by a racquet. System = ball				
5					
6	You press a book on a table up against the wall. System = book		Hint: 4 interactions		
7	A book is sitting on top of a cart. The cart is at rest. System = cart				

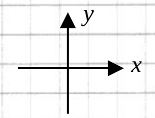
SPH4U: Forces in 2-D

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

A: Tilted Forces

A hand pulls on a cart with a force, $\vec{F}_a$ = 5 N [Left] and a string pulls on the same cart with a force $\vec{F}_t$ which is directed [Right 30° Up]. The cart remains at rest on a level surface.

1. **Represent.** Draw the ID and large, clear FD for this situation. Add a component triangle into the FD for the force $\vec{F}_t$. (Reminder: an ID only shows the objects and interactions)

ID	FD
	

2. **Explain.** In the *x*-direction, how are the forces or components of forces balancing?

3. **Predict.** How do you think the magnitude of $\vec{F}_t$ compares with $\vec{F}_a$? Explain your reasoning. Use a calculation to predict a value for F_t.

4. **Reason.** Now it's time to get two 10-N spring scales, one dynamics cart, and one protractor. What is the instrumental uncertainty of your spring scale?

Spring Scale Tips:
1) Hold the scale in the vertical or horizontal position in which it will be used. Calibrate it to read 0 N with no forces applied.
2) Do not twist it when forces are applied. The internal pieces may bind and give a false reading.

5. **Test and Evaluate.** Create this situation using two spring scales for $\vec{F}_a$ and $\vec{F}_t$, and a protractor. Measure the size of $\vec{F}_t$ and record it here with its uncertainty. Does this result agree with your prediction?

6. **Represent.** Write an equation for Newton's 2nd Law in the *x*- and *y*-directions. Get in to the habit of always showing the *sin* or *cos* functions for your components. The *x*-component of the second law is done as an example for you!

   $F_{netx} = ma_x$

   $F_t \cos\theta - F_a = 0$

7. **Reason.** Isaac says, "Finding the size of the normal force is easy! It is the same size as the force of gravity." Do you agree or disagree? Explain. (Do you need to make any changes to your FD above?)

B: Forces on a Tilt

The cart is at rest on a surface inclined at an angle θ to the horizontal. It is held in place by a force, $\vec{F}_t$, which will be provided by your spring scale and is parallel to the incline. Later, you will use the incline set up at the front of the room.

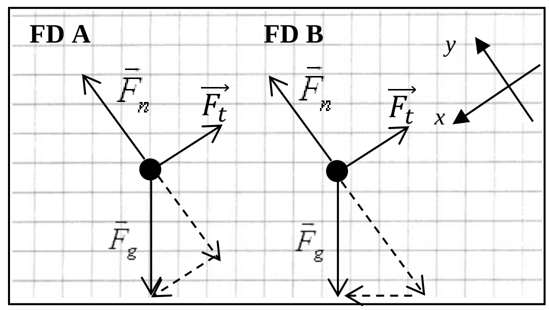
ID

1. **Represent.** Draw an ID for the cart in this situation.

2. **Reason.** Isaac says, "I'm thinking about how to draw the force diagram for this situation. The normal force should be pointing vertically upwards, right?" Do you agree or disagree with Isaac? Explain.

Choosing a coordinate system. We choose a coordinate system to help us think about and analyze the effects of forces in each direction. Any choice of coordinate system is technically correct, but some choices make for easier understanding. In most cases, the best choice of coordinate system is one that lines up with the acceleration vector for the system.

Draw the components of a force vector using dashed lines or a different colour so the components won't be mistaken for another, new force. Make sure the components are **parallel to each axis** of the coordinate system.

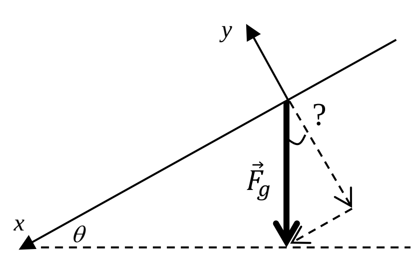


3. **Represent.** In this situation, if the cart was free to move, in what direction would it move? Use phrases like, up/down the incline, or into/out of the surface.

4. **Reason.** For this situation, we have chosen a coordinate system that lines up with the inclined surface. Based on this choice, which force diagram shows the appropriate set of components for the force of gravity vector? Explain and cross out the inappropriate FD.

5. **Reason.** Which forces, or components of a force, balance each other? Explain and add tick marks to the appropriate diagram above.

6. **Explain.** We want to analyze the force of gravity vector carefully. It has been redrawn with a large set of coordinate axes to the right. The dashed line shows the horizontal and θ is the angle of the incline. Use your powers of grade 9 geometry to find the angle marked "?". Explain your work with simple phrases written directly on the diagram. Include this angle in your component triangle of the appropriate force diagram above.



7. **Predict.** Measure the angle of the incline and the weight (F_g) of your cart. Use the *x*-component of Newton's 2nd law to predict the size of $\vec{F}_T$.

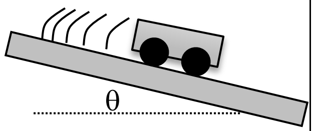
8. **Test.** First, decide on the instrumental uncertainty of the device you will use to test your prediction. Next, use the incline at the front of the class to measure the magnitude of $\vec{F}_T$. How does this compare with your prediction?

SPH4U: Understanding 2-D Forces

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

A: Rolling Down

1. **Reason.** A cart is rolling down an incline. The force of friction is very small. What coordinate system is best to use for analyzing this situation? Explain.

Sketch	ID	FD	Newton's 2nd Law
			

2. **Represent.** Draw an ID and FD for this situation. Write a complete expression for Newton's 2nd Law in the *x*- and *y*-directions. Make sure you show your trig!

3. **Evaluate.** Page 54 of your handbook has rubric to help you evaluate your work in our forces unit. Use the rubrics to evaluate your ID, FD and 2nd law expressions above. Record a mark in each box and use **a different colour** to make improvements to your work based on the rubric criteria. You should now have top-notch 5/5 work!

The force of gravity acting on an object with mass, *m*, can be found using the expression: $F_g = mg$, where g = 9.8 N/kg and is called the **gravitational field strength.** Be careful not to confuse this expression with $F_{net} = ma$: they are not closely related.

Calculation advice: When you are making calculations using forces and Newton's 2nd law, always start with a component equation for Newton's 2nd law. Continue your work using symbols for as long as possible, so long as the expression does not get really messy. Only when you have isolated a final result or an important middle result should you substitute values into your equation. You might not be used to working this way, but once you are, it will save you a lot of work.

4. **Calculate and Predict.** An incline with a cart and motion detector is set up at the front of the class. Calculate the acceleration of the cart when it is released and rolls down the incline. Estimate an uncertainty for your result.

5. **Reason.** Your model for the cart on the incline contains a very important assumption that is not 100% correct. Describe (don't calculate) how you could improve your model. How would this change your acceleration prediction?

6. **Test.** Use the equipment to test your prediction for the acceleration while the cart travels up and then down the incline. Use the computer to find the slope of the velocity graph. Does the result agree with your prediction? Explain.

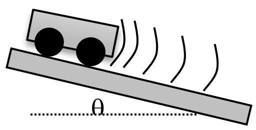
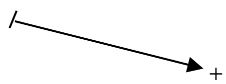
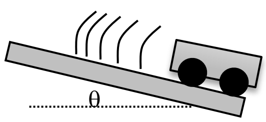
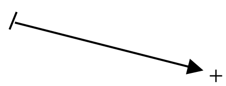
B: The Friction Question

A cart with a friction pad rolls up and then down an incline. We define three events: (1) the cart is released, (2) the cart reaches the highest point, and (3) the cart reaches the bottom just before stopping. Now let's improve our model for the cart and include a constant force of friction.

1. **Represent and Reason.** Draw an interaction diagram for this situation. Is the ID any different when the cart is rolling up the incline, compared with rolling down?

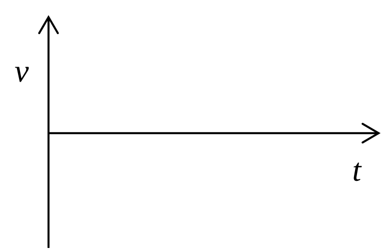
ID

2. **Represent.** Complete the chart below for this situation.

Sketch	**Motion Diagram**	**Force Diagram**	**Newton's 2nd Law**
			
Sketch	**Motion Diagram**	**Force Diagram**	**Newton's 2nd Law**
			

3. **Evaluate.** Use the rubric and assign a mark to the ID and each box in the chart above. Then use a **different colour** to make any improvements.

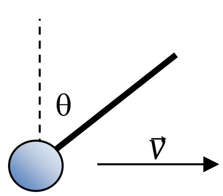
4. **Predict**. Compare the magnitude of the cart's acceleration when it is going up the incline to when it is going down. Which is bigger? Justify your prediction. Sketch a velocity graph showing the three events. We will test this later together as a class.



C: The Floating Ball

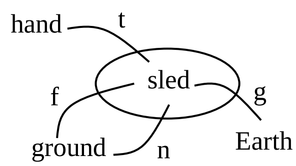
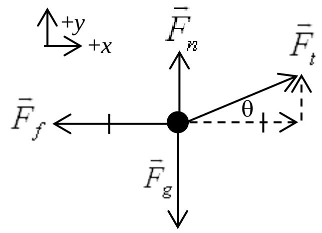
A ball is tied to a string. Emmy says, "Watch this. I can pull the ball with the string at an angle, like this, so it moves **horizontally** through the air." Isaac captures this on video and examines one frame of that video, which is shown in the sketch below. Isaac says, "I don't understand how this is possible. The forces simply don't work out properly."

1. **Reason.** Use the force diagram to carefully explain to Isaac how the ball must be moving. Air resistance is negligible.

	ID	**FD**	**Newton's 2nd Law**
			

A: You Must Learn the Ways of the Forces (and Come with Me to Alderan)

Working with forces is a fundamental skill for the study of physics. Let's focus on building your skills and your understanding of our basic techniques. Study the example below carefully.

Situation	ID	FD	2nd Law components
You drag a sled along a patch of rough ground with a constant speed. The rope for the sled makes an angle θ with the horizontal.			$F_{net\,x} = ma_x$ $F_t \cos\theta - F_f = 0$ $F_{net\,y} = ma_y$ $F_n + F_t \sin\theta - F_g = 0$

1. **Explain.** In the equation: $F_t \cos\theta - F_f = 0$, does the symbol F_t represent a quantity that has a magnitude, a direction or both?

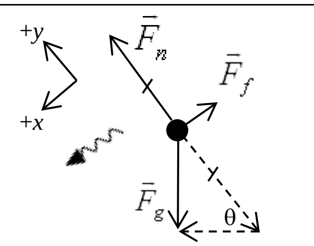
2. **Explain.** Why is it incorrect to write: $\vec{F}_t \cos\theta - \vec{F}_f = 0$?

3. **Interpret.** How many interactions does the ground participate in? How is this represented in the ID?

4. **Explain.** Describe what the two dashed arrows tell us about the force of tension.

B: Slides Rule!

1. **Represent.** Draw an ID for the situation below.

Situation	ID	Incorrect FD	Corrected FD
A child travels down a slide at the playground and speeds up. There is some friction. The slide makes an angle θ with the horizontal. System = child			

2. **Explain.** Albert has made a first attempt to draw an FD for this situation. You tell him that there are problems, but he can't figure out what they are. Explain carefully to Albert the problems **with his reasoning** that led to the two distinct errors in the FD. Draw a corrected FD. (Hint: if you need a hint, turn the page – but don't turn yet!)

(*continued on the next page*)

(Hint: the dashed arrows and the angle!)

3. **Solve.** The child has a mass of 21 kg and experienced a friction force of 87 N. The slide is inclined at 38° to the horizontal. Find the acceleration of the child. Complete Parts C, D and E of the solution process. (answer = 1.89 m/s^2)

C: Word Representation

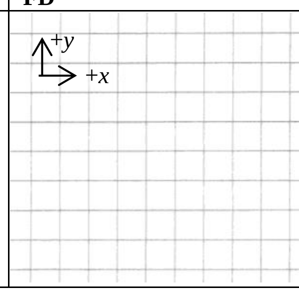
Describe motion (no numbers), explain why (explain what forces balances or don't balance), assumptions, estimate result (no math)

D: Mathematical Representation

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

C: Shot Put

An athlete throws a shot put (very heavy ball, 4 kg) in an Olympic competition. She exerts a force of 97 N at an angle of 37° to the horizontal. The shot put moves in a straight line while it speeds up.

Situation	ID	FD	2nd Law components
			

1. **Represent.** Complete the representations in the chart above. Note that the shot put is not likely to slide against her hand, so just use a single applied force. Use your rubric and record a mark in each box. Make any corrections or improvements in a different colour.

2. **Solve.** What is the magnitude of the acceleration of the shot put? (Hint: find the *x* and *y* components first) Complete Part D of the solution process below. (answer = 20 m/s^2)

SPH4U: Newton's Third Law

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

A: Forces as Interactions

When two objects affect one another, we say that they *interact*. Interactions involve a push or a pull between objects which we call *forces*. This brings us to a very important idea: Newton's 3rd law.

Whenever two objects interact, they each exert a force on the other. These two forces are the two parts of a **single interaction**. We will call these two forces a *3rd law force pair*. The forces in a 3rd law force pair share some important characteristics:

- they have the same magnitude
- they point in opposite directions
- they are the same type of interaction (gravitational, normal, etc.)
- they arise and act simultaneously
- they involve the same pair of objects

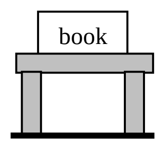
This understanding of interactions is known as *Newton's 3rd Law*. Please **never** use the words *action* or *reaction* when describing forces. To do so is both old-fashioned and wrong.

B: Book Learnin'

One of the exciting things about studying physics is that as your understanding grows, the physics of very simple situations becomes much more nuanced and subtle. Let's think about your physics book at rest upon a table.

1. **Represent**. Draw an ID and FD for the system of the book.

To show better the details of an interaction, we can use a more specific force notation which we will call *3rd law notation*. For example the earth interacts with the textbook gravitationally and we can symbolize this as: $\vec{F}_{g\,E\text{–}B}$, which reads: "the force of gravity of the **earth** acting on the **book**".

Sketch	Interaction Diagram	Force Diagram
		

2. **Represent**. Label the forces in your force diagram using this new notation.

Note that if you have done this correctly, all the subscripts for the forces on one object will end with the same letter. Double check this every time you use this notation.

3. **Reason.** Isaac says, "I think gravity and the normal force make up a third-law pair in this situation. Just look at the size and direction of the forces." Do you agree or disagree with Isaac? Explain.

4. **Reason**. Emmy says, "In other situations, gravity and the normal don't always have the same size. Why do they here?" Explain to Emmy.

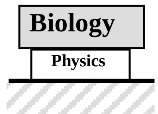
5. **Reason**. Albert says, "So if gravity and the normal force are not members of the same 3rd-law pair, is there a 3rd-law partner for $\vec{F}_{n\,T\text{–}B}$?" Explain what it is and why it doesn't appear on this force diagram.

C: The Stack O' Books

Your homework is piling up – your **slender** physics text is sitting on the table and your **massive** biology text is on top.

1. **Represent.** Draw a **single** interaction diagram for this situation. We will consider the bio book and physics book as two separate systems: circle each.

2. **Represent**. Draw a force diagram for each book. (Hint: you should draw five forces in total!) Whenever we study the forces of more than one object, use the 3^{rd} law notation introduced above.

Sketch	Interaction Diagram	FD Bio text	FD Physics text
			

A *contact force* is one that is evident only when two objects are in contact. A *non-contact* force is evident even when the two objects are not in physical contact.

3. **Represent**. Are there any 3^{rd}-law force pairs appearing in the two diagrams? If so, indicate these with a small "×" beside each force vector.

4. **Reason**. Rank the magnitude of the forces appearing in the two force diagrams from smallest to largest. Explain your ranking. (Check: do the force diagrams above match your rankings?)

5. **Explain.** Explain to a grade 10 student in a simple way why the normal force of the table on the physics book is the largest force.

6. **Reason**. Is the table interacting with the biology text in any important way? Explain.

7. **Reason**. Compare the force diagram for the physics text from parts B and C. Which forces changed when the biology text was added and which remained the same? Explain.

8. **Reason.** In a similar situation, the same stack of books is sitting on a scale. Which force from the diagrams above should you use to predict the reading on the scale?

SPH4U Homework: Magnets and the Third Law! Name:

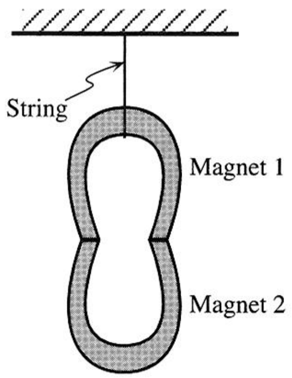
Let's explore our understanding of the third law using a new interaction: magnetism! We can treat magnetic interactions just like we do gravitational interactions.

A: Two Horseshoes

One magnet is supported by another identical magnet that hangs from a string.

1. **Represent.** Draw a single interaction diagram that includes the two magnets. Circle each magnet as a separate system.

2. **Represent.** Draw a FD for each magnet. Make sure you use the complete 3rd law notation for the forces. Draw an × or ×× to show any third law pairs of forces. (Hint: there should be four forces on the first FD)



ID	FD Magnet 1	FD Magnet 2

3. **Reason.** Suppose that the two magnets were replaced by stronger magnets of the same mass. Describe any changes to the ID. Draw revised FDs for each.

FD	FD

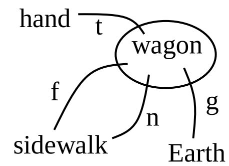
4. **Reason.** Can a magnet exert a non-contact force on an object? Explain.

5. **Reason.** Can a magnet exert a contact force on an object? Explain.

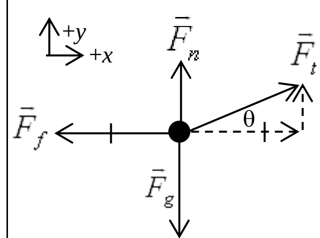
6. **Explain.** How could you use a magnet to exert both a contact and a non-contact force on another magnet?

SPH4U Forces Unit Rubrics

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 or components are shown with a "tick" mark. • Components are shown using dashed lines (or coloured lines) with arrowheads and an angle is shown at the tail of the vector. • 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 component equation (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 • Force components are written with a *sin* or *cos* function • Direction of the force or component is shown using the sign convention. • If there is no acceleration, the equation equals zero.	$F_{net\ x} = ma_x$ $F_t \cos\theta - F_f = 0$ $F_{net\ y} = ma_y$ $F_n + F_t \sin\theta - F_g = 0$

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

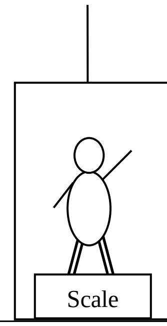
SPH4U: Weight and Acceleration

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

A: The Elevator

You may have noticed a curious sensation while travelling in an elevator. At certain times, it feels like your weight is changing. Since you are such a curious student, you decide to investigate this. You step into an elevator at the ground floor of a tall building and stand on top of a bathroom scale that gives readings in newtons. You haven't pushed any buttons yet and you look down at the scale.

Sketch | ID | FD



1. **Represent.** Draw an ID and FD where you are the system while the elevator is at rest on the ground floor.

2. **Reason.** Marie suggests, "There should be another force on the FD showing the upward effect of the cable." Do you agree with Marie? Explain.

In the world of physics, weight is a synonym for the force of gravity: $F_g = mg$, where the gravitational field strength g = 9.8 N/kg. Our physical sensation of weight corresponds not to the force of gravity, but to the force supporting us (often a normal force). The reading of a bathroom scale measures this supporting force which we call our **apparent weight**.

3. **Solve.** Use Newton's 2nd law ($F_{net} = ma$) to determine your apparent weight in this situation. (If you like, assume your mass is 65 kg).

4. **Evaluate.** Is your weight different from your apparent weight in this situation?

B: Going Up!

Now you press the button in the elevator and go for a ride! The elevator starts speeding up as it begins your trip to the 20th floor.

ID | FD

1. **Reason.** Isaac says, "In this situation we need to add another upwards force to the force diagram since you are now accelerating upwards." Do you agree or disagree with Isaac? Explain and draw a revised ID and FD for this situation.

2. **Predict.** Will the reading of the scale increase or decrease compared to the when you were at rest? Explain without using any math.

3. **Test.** Hang a heavy mass from a spring scale and gently accelerate it upwards. Compare the scale's reading (apparent weight) with the weight of the object (force of gravity). Does this agree with your prediction?

4. **Solve.** The elevator is accelerating at a rate of 1.5 m/s^2. Use Newton's 2nd law to determine your apparent weight. How does this compare with your weight?

C: The Trip Up

As you are going up, somewhere around the 2nd floor you notice the scale reading returns to normal.

1. **Explain.** How has the motion of the elevator changed? Use your spring scale and mass to help explain.

The elevator is near the 19th floor and continues to move upwards, but you notice another change to the scale reading as the elevator is slowing down.

2. **Reason.** Emmy comments, "I think the upwards force must still be larger than the downwards, or else the elevator would not be moving upwards." Respond to Emmy and draw a new ID and FD.

ID	FD

3. **Predict and Test.** How will the reading of the scale change as the elevator goes from constant velocity to slowing down? Test this with your mass and spring scale. Describe your observations.

4. **Solve.** The elevator slows at a rate of 3.4 m/s^2. Determine your apparent weight.

5. **Summary**. How did the interaction and forces change in the different situations you have explored?

6. **Summary.** In general, how is apparent weight related to the acceleration of an object?

D: A Strange Elevator

You wake up to find yourself in a very strange elevator with no buttons, lights or windows. You are floating just above the scale and have lost the sensation of weight. The scale itself reads zero. Offer two possible explanations for this very curious situation.

1)

2)

SPH4U: Frames of Reference

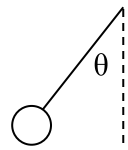
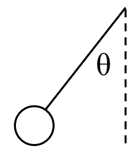
Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Your friend is standing on a bus that is travelling east and speeding up at a constant rate along a level road. While this is happening she holds up a rope with a ball attached to the end of it. The ball is allowed to hang freely. Assume east is to the right. Answer the following questions while the bus is accelerating and the ball hangs in a steady way (not swinging around!)

1. **Represent and Explain.** Draw an interaction diagram for the ball according to an observer in each frame of reference. Are there any differences between the two interaction diagrams?

2. **Represent.** Draw a force diagram for the system of the ball according to an observer in each frame of reference. **Only include forces supported by your interaction diagram.** In which frame is an acceleration vector appropriate?

3. **Reason.** Newton's First law fails to explain what's going on in which frames of reference. How does it fail to do so?

Earth frame	Bus frame
Sketch 	**Sketch** 
ID	**ID**
FD	**FD**

The rules we have learned for forces and motion breakdown in accelerating frames of reference producing contradicting results like the one above. To "patch things up" and help our rules work again, we introduce a convenient fiction - a *fictitious force***.** A fictitious force is **not a part of any known interaction** and thus is not a real force, but we may work with it as if it was. Such a force is only ever needed in an accelerating frame of reference and should never appear in a FD from an observer who is not accelerating.

4. **Represent.** Draw a revised FD for the bus frame of reference. Add a fictitious force, F_{fict}, such that FD agrees with the motion of the ball according to Newton's First Law. You have saved the law!

5. **Explain.** How does the direction of the fictitious force compare with the acceleration of the bus, a_b, as measured in the earth frame?

Revised FD

6. **Summarize.** Think of other situations where you have been accelerated. Except when in free fall, we feel as if we are somehow being pushed. In all these situations, how does the direction of your acceleration compare with the direction of the sensation you feel?

7. **Represent.** Using the Earth frame of reference, write an expression for the *x*- and *y*-components of Newton's 2^{nd} law. In your second step, replace F_g using $F_g = mg$. Don't forget your trig!

8. **Reason.** Imagine we had a photo showing the ball and string that allows us to measure the angle θ. Our goal is to solve for the acceleration of the bus as measured in the Earth frame of reference. Examine the two equations you wrote above. Are you able to use either of them (individually) to solve for the acceleration? (Remember: θ is our only measurement).

There are times when Newton's 2^{nd} law gives us a pair of equations with two unknown quantities in each. This is a system of two equations with two unknowns, examples of which you have seen in your math classes. If this is the case, our goal is to algebraically eliminate one quantity from the system of equations and solve for the other. Use you math skills to isolate one unknown and substitute it into the other equation.

9. **Reason.** Which quantity would we like to eliminate from our equations? (Hint: don't choose mass)

10. **Solve.** Use your algebra skills to eliminate one unknown and create an equation that will allow us to predict the acceleration of the bus. (Hint: when you are done, θ and *g* should appear only once in your equation)

11. **Explain.** Why was it helpful to write the force of gravity as *mg* and not worry about the mass?

B: Fictitious Forces and Acceleration

1. **Summarize.** How does the direction of your fictitious force compare with the direction of the acceleration?

2. **Summarize.** What diagrams do the two observers agree on? Consult your table on the first page.

3. **Summarize.** In what kind of reference frame is fictitious force is introduced to fix Newton's First law?

SPH4U: Strings and Composite Objects

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

How do strings do their thing? Let's find out!

A: String Theory

You need three identical spring scales. Connect all three spring scales into a chain. Each hook of the scale represents a piece of "string material" and the springs inside the scale represent the interaction between the pieces of string material.

1. **Observe**. Hold on to each end of the chain of scales and stretch them **horizontally** along your table. How do the readings of each scale compare? What happens to the readings when you pull harder?

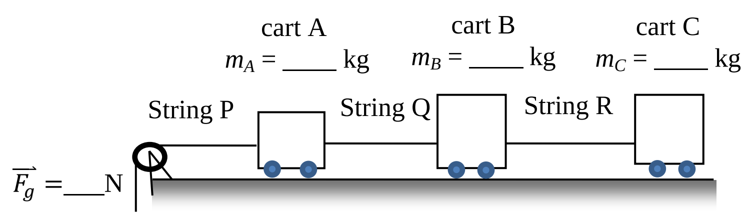
2. **Reason.** What is the reading on the scales? How hard does each end of the string pull on each of your hands? What law does this result come from?

3. **Reason.** Pull on **just one** end of your "string" and describe the force readings. Is it possible to have any **significant** amount of tension in a real string if we pull on only one end?

In physics, we often use the **ideal string model** and assume that real-world string: (1) is massless, (2) does not stretch, and (3) exerts equal and opposite forces on the objects it connects. Consequently, we think of a string as producing a single tension interaction between the two connected objects, an interaction which obeys Newton's 3rd law. Under these assumptions, we will **not** consider string as an independent object and will never write the word "string" in an interaction diagram: we will simply indicate a tension interaction.

B: Composite Objects

Most objects are made up of millions of smaller parts, all interacting together. With so many interactions, why can we actually do simple physics and not get bogged down? Consider the situation shown below. A track set up at the front has three carts connected together by strings.

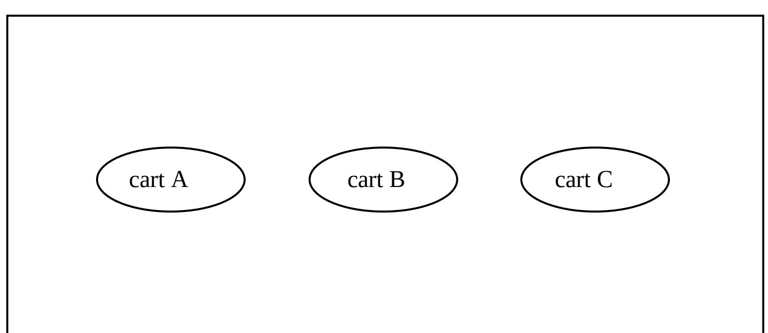


1. **Record.** Record the mass of each cart and the force being applied to the first cart directly on the diagram.

2. **Observe.** When the mass is released, what is the state of motion of the carts?
   How do their velocities or accelerations compare?

A *composite object* is any object whose parts move in a similar way, often with the same acceleration.

3. **Represent.** We will start by considering each cart as a separate system (systems A, B and C). Complete one interaction diagram for the three blocks. Use your ID evaluation rubric and give your ID a mark out of 5.



4. **Represent.** Which system will have the simplest FD? Start by drawing a FD for that system. Use your FD evaluation rubric and give your FD a mark out of 5. **Then** draw a FD for systems B and A. Indicate any third law pairs with an × or ××.

System A	System B	System C
$m_A =$	$m_B =$	$m_C =$

5. **Represent.** Use a new colour to draw a system boundary (circle) consisting of carts B and C together in the interaction diagram on the previous page. Draw a FD for this new system that we will call system D.

6. **Explain.** Use the words "internal" and "external" to help explain how to use the interaction diagram to decide which forces should appear on the FD for system D.

System D

$m_D =$

7. **Represent.** Use another colour to draw another new system in the interaction diagram consisting of carts A, B and C together. Draw the force diagram for system E. Indicate the mass of the system.

8. **Reason.** Which system has the simplest force diagram for the purpose of finding the force of tension in string P? What about for string Q? for string R?

System E

$m_E =$

C: Comparing Tension

How do the three forces of tension in this situation compare? Use data from earlier in the lesson to complete this section

1. **Reason.** With this given information, which single system can we analyze and successfully solve for some unknown quantity? (Hint: think about which quantities know and don't for each system. We can't solve for any forces yet!)

2. **Represent and Solve.** Write the expression for Newton's 2nd law in the *x*-direction for the system you have just chosen. Label the F_{net} and *m* with subscripts for the appropriate system. Now solve for this first unknown quantity.

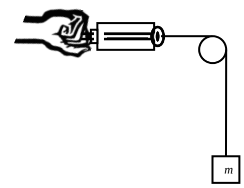
3. **Calculate.** Use Newton's 2nd law to predict the size of each force of tension. Be sure to label your quantities carefully.

SPH4U: Tension and Pulleys

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

A: Physics Pulleys

You will need a pulley, a piece of string, a 500 g mass and a spring scale. Set up your equipment as shown in the diagram. **Calibrate your scale!**

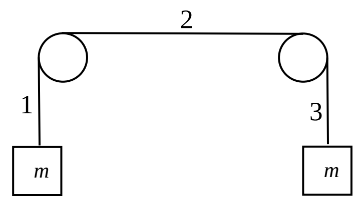


1. **Observe.** Change the angle of the string that passes over the pulley. Describe what you observe.

2. **Reason.** Devise a rule that explains how an *ideal* physics pulley might affect the magnitude and direction of the force of tension in a string.

Ideal Pulleys Approximation:

B: Testing String Theory



1. **Predict.** Consider the two-pulley situation shown in the next diagram which uses two 500 g masses. Suppose we measure the tension in the string at the three positions indicated. Predict the values of those three tension measurements. Provide a rationale for each. **Remember: you don't need to agree with your group about predictions!**

Prediction	Rationale
(1)	
(2)	
(3)	

2. **Test and Evaluate.** Use the equipment set up at the front of the class to test your predictions. Record your results along with uncertainties. Do your results agree with your predictions? Offer an explanation for the results you found.

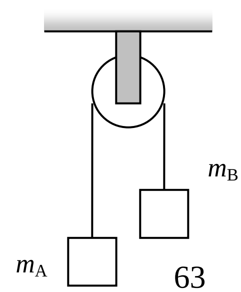
Results	Explanation

3. **Reason.** Does a spring scale measure the net force? Explain using your observations.

Tension in a string (or any object) is produced when the opposite ends of the string are pulled apart. The size of the force of tension is the same throughout the string and is equal to the size of the force pulling at each end. For example, a 5 N force of tension means a 5 N force pulling outwards on each end of a string.

C: The Atwood Machine

An Atwood machine consists of two objects tied together and suspended over a pulley. For this part of the investigation, you will use the equipment set up at the front of the class.



1. **Predict.** The two objects have the same mass. You give a gentle pull on the string to start the system moving. Predict the motion of the mass **after** you let go of the string. Justify your prediction.

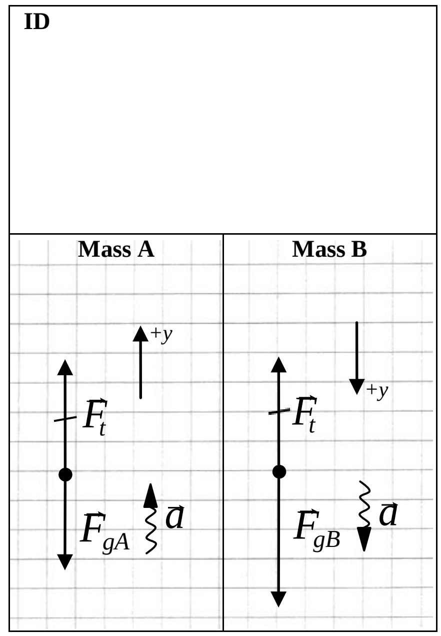
2. **Test.** Try it out. Describe your observations. Do they agree with your prediction?

3. **Predict.** You will add an extra weight to object B. How will B move after you release it? How will the motion of the two objects compare? Justify your predictions.

4. **Test.** Try it out. Describe your observations. Do they confirm your predictions?

5. **Represent.** Draw a single ID for the two objects. Treat each object as a separate system.

6. **Reason**. The FDs for the two objects with unequal masses has been drawn for you. Rank the magnitude of the three forces. Explain your ranking using Newton's Laws.



7. **Represent.** Write a complete expression for Newton's 2nd Law for each object. Note that a sign convention has been chosen such that the positive direction is the direction of the acceleration of the **system.** Be sure to label the appropriate quantities with subscripts A and B.

8. **Solve and Test.** Algebraically eliminate F_T from the above two equations and solve for the acceleration of the objects. Use the masses from the Atwood machine set up in the classroom and solve for the acceleration. Test this result using the motion detector.

9. **Solve and Evaluate.** Now go back and solve for the force of tension. How does this result compare with your ranking in question #6? Explain.

SPH4U: Friction!

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

We normally think of friction as the force that stops things from moving. This is in many respects still true, but we must also realize that friction is the force that is usually responsible for starting things moving too!

A: Rubbing the Wrong Way?

Find a convenient, hand-sized object. Place the object on the flat palm of your hand. Keep your hand completely horizontal and cause the object to move horizontally and speed up **with** your hand (no slipping).

1. **Reason.** Marie says, "At first I thought a horizontal *normal* force causes it to accelerate. But then I remembered that a normal force is always perpendicular to the surfaces. It doesn't make sense to have a horizontal normal force here." Do you agree with Marie? Explain.

2. **Reason.** Emmy says, "In this situation a friction force must act in the forwards direction." Albert responds, "That's not right. Friction always opposes an object's motion. It should point in the backwards direction." Who do you agree with? Explain.

3. **Predict.** What would happen to your object if there was *no friction at all* between it and your hand? Explain.

4. **Test.** Try this out with the equipment at the front of the class. Record your observations. Do they support your prediction? Do you need to revise any of your earlier answers?

5. **Represent.** Draw an ID and FD for your object while it is speeding up.

ID	FD

Friction is a contact force that tries to prevent two surfaces from sliding relative to one another. If there is no slipping of the two surfaces, *static friction* **may** be present. If the two surfaces are slipping, *kinetic friction* is present.

B: Two Kinds of Friction

1. **Represent.** Use a friction box with a bit of stuff in it as your object. Place your object on the table. Exert a small force on the object using a 5N-spring scale such that it slides at a constant velocity. Draw a FD for it while sliding.

FD

2. **Explain.** Why is the spring scale reading the same size as the force of *kinetic friction?*

3. **Explain.** You might have noticed that reading on the spring scale jerked lower as soon as your object began to slide. (If you didn't notice this, apply a small and gradually increasing force or find a heavier object.) What does that higher initial reading tell us about the friction between your object and the table? (Hint: Remember there is *another* type of friction!)

The force of friction depends on the characteristics of the surfaces involved (as represented by the coefficient of friction, μ), and how hard the surfaces are pressed together (the normal force, F_n). The two forces of friction can be found from the two expressions, $F_{fk} = \mu_k F_n$ and $0 < F_{fs} \le F_{fsmax}$, where $F_{fsmax} = \mu_s F_n$.

4. **Calculate.** Make measurements and determine the coefficient of kinetic friction for your object on the table.

C: Friction and the Ramp

You need a track and a friction box that produces about 1-3 N of static friction. Our first goal is to find the coefficient of static for the box on the track when the surface is **horizontal**. You will pull on your object and observe the largest possible force of static friction.

1. **Represent.** Draw an ID and FD for this situation. (Hint: is the object at rest?)

2. **Observe and Calculate.** There is a lot of uncertainty in this measurement, so record a high possible value and low possible value for your friction measurement and calculate a high and low possible value for the coefficient. Show your work.

ID	FD

3. **Represent.** Now we want to understand the situation when the box is at rest on the track and you are increasing the angle of the incline (you are no longer pulling on it). Draw a FD for the box at rest on the track at an angle θ to the horizontal. Let the *x*-axis be parallel to the incline.

FD

4. **Reason.** How will each force change when the angle of the incline increases? Explain.

F_{gx}	F_{gy}
F_n	

In many physics problems, it is very helpful to use algebra (symbols only) until you reach the final step or an important middle point. In some situations, symbols will divide away or add to zero, creating a simple expression and revealing that certain quantities that you thought you needed to complete the calculation are not necessary at all. You have spent all these years in math class working on your algebra skills; it's time to unleash their power!

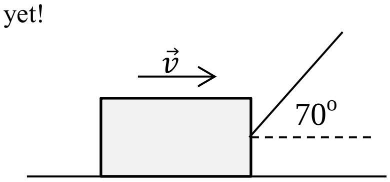
5. **Analyze.** Now we want to focus on the moment when the incline is tilted up to the highest angle **before** the object begins to slip. Write out the *x*- and *y*-components of Newton's second law. Use the two 2nd law equations and the expression for the maximum value of static friction ($F_{fsmax} = \mu_s F_n$) to create an algebraic expression that relates the angle of the incline to the coefficient of static friction. You will need to substitute one equation into another to eliminate quantities that you are not interested in (like F_f and F_n).

6. **Predict**. Use your previous result to predict high and low angle values for the angle at which your object will begin to slide as we raise the incline.

7. **Test.** Set up your track on the incline at the front. Record the angle at which it begins to slide. Do your observations confirm your prediction? Note that there are large uncertainties (a few degrees) in this experiment.

D: Testing Friction and Angles

In your next experiment, you will pull your friction box along the table with a constant velocity using a pulling force that makes a 70° angle to the horizontal! Add a 1 kg mass to your friction box. Don't do this yet!



1. **Reason.** What happens to the size of the force of kinetic friction when you pull the box with a constant velocity at a 70° angle compared with pulling it horizontally? Use appropriate **physics diagrams** to support your guess. Do not perform any calculations!

2. **Crazy Guess.** You pull the box horizontally with just enough force to cause it to move with a constant velocity. Next, you pull the box at a 70^o angle with just enough force to cause it to move with a constant velocity. How do the sizes of the two pulling forces compare? Don't use any math (algebra or calculations), just discuss the ideas involved. Are you able to come up with a definitive comparison?

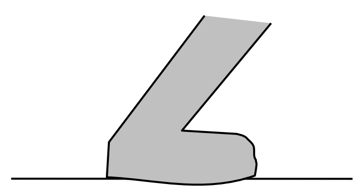
3. **Prediction.** Mathematically develop an exact prediction for the size of the 70^o pulling force using measurements of μ and m for your friction box. Don't test the 70^o situation yet!

4. **Test.** Call your teacher over to witness your test. Pull the box at a 70^o angle. Record your observations.

5. **Evaluate.** Do your observations agree with your prediction? Explain.

E: Friction and You

What is the cause of our motion when we walk, drive, or ride a bike?



1. **Observe.** Have one group member walk slowly. Watch carefully: does their back foot slide against the ground?

2. **Reason.** Consider the system of the back foot while walking. Have that person freeze in place as their back foot is pushing against the ground. What is the back foot interacting with?

3. **Explain.** What force is pushing forward on the foot? Ultimately, this is the external force responsible for making the system of your body accelerate forward.

4. **Reason.** Isaac says, "According to my third law, there is an equal size friction force of the foot on the earth. Why don't we notice this?" Explain to Isaac why we don't notice the effect of this force.

SPH4U: Going in Circles?

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

What makes the world go 'round? Let's find out!

A: Observing Circular Motion

Let's find out how forces in different directions affect the motion of the intrepid physics buggy! A reminder - **velocity** has two parts: a magnitude (speed) and a direction.

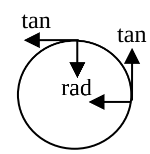
1. **Reason and Observe.** (a) Think about your experiences so far in physics: when a force acts on an object in a direction **parallel** to its motion, how does its velocity change? (b) Attach a piece of string to the buggy around its middle and fix the other end to a spot on the floor with your finger. This exerts a constant, horizontal force on the buggy in a direction **perpendicular** to the direction of the buggy's motion. How does its velocity change?

Forces Parallel	**Forces Perpendicular**
Speed: Direction:	Speed: Direction:

2. **Recall.** What is the definition of acceleration?

3. **Reason.** In which case(s) above is the buggy accelerating? Explain.

There are two important directions in circular motion: the *radial* direction (inward or outward along the radius of the circle) and the *tangential* direction (forwards or backwards tangent to the circle). When we set up a coordinate system, we will still label an *x*- and - and *y*-axis, but we might refer to these axes as the tangential or radial directions.



4. **Reason.** Create a principle describing the effect of forces on an object's speed and direction.

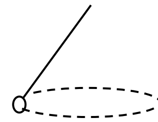
Speed and Direction Principle:

5. **Represent and Reason.** Swirl a marble around inside a roll of masking tape. Once it's going, hold the roll of tape still and observe. We will neglect the small amount of friction which slows down the marble after you stop "swirling".
   a) Draw an ID for the system of the marble.
   b) Draw a force diagram for the marble at two moments in time: when it is moving towards you and when it is moving away from you. Draw it from a head-on point of view (as if your eye was at table level.
   c) What forces or components of forces balance?

ID	FD (head-on, towards)	FD (head-on, away)

   d) Describe the direction of the net force experienced by the marble while it travels in circles inside the tape.

6. **Observe and Reason.** Tie an object to a length of string and swing it in a **slow**, **horizontal** circle. (Don't hit anyone!)



a) Is there any acceleration in the vertical direction? Explain.

b) Is there any acceleration in the horizontal direction? Explain.

c) Draw an ID and a FD for the system of the object.

d) What forces or components of forces balance?

e) Isaac says, "I think the net force points up at an angle, along the string." Marie says, "I think it points horizontally." Who do you agree with? Explain.

ID	FD

B: Making Rules and Breaking Rules

1. **Reason.** Devise a *provisional* rule for the direction of the net force of an object moving in a circle at a constant speed. (*Provisional* means temporary or likely to change.)

Provisional Rule #1:

2. **Describe.** Think about your experience turning a corner in a car. How does that feel?

Provisional Rule #2: *When an object moves in a circle there is a radial force acting outwards, away from the centre.*

Provisional Rule #3: *When an object moves in a circle, there must be a tangential force forwards, in the direction the object is moving.*

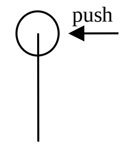
We don't know yet which of these rules are correct. In science, we make observations, develop theories (rules) and then test them out. In the following experiment we will look for evidence which supports or refutes these three rules.

3. **Predict and Test**. In a moment you will attach a hover puck to a string. The hover puck is given a short push to start it moving. The end of the string is held fixed on the ground.

(a) Predict how the puck will move **after** the push.

(b) Test your prediction and describe the motion of the puck. Does it agree with your prediction?

(c) Draw an ID and a FD for the puck **after the push** from a top view (from above).

Sketch	ID	FD (top view)
		

4. **Reason.** Each provisional rule makes a prediction about the forces during circular motion. Based on your observations during this investigation and the force diagrams you drew, which rules are confirmed and which are refuted? Describe the evidence you use for each rule.

Provisional Rule #1	Provisional Rule #2	Provisional Rule #3
Prediction: There is a net force in the radial inwards direction.	**Prediction**: There is a force in the radial outwards direction.	**Prediction**: There is a force in the forwards direction.
Conclusion:	**Conclusion:**	**Conclusion:**

5. **Reason.** Provisional rule #2 is a very popular one! When we are in a car that turns a corner, we feel a "force" pushing us in the radial outwards direction. What kind of frame of reference is this observation made from? What kind of "force" explains this outwards feeling? Is there any interaction that explains this "force"?

6. **Reason.** Based on your observations, elevate one of the provisional rules to an official rule. Mention what uniform circular motion means.

Net Force and Uniform Circular Motion:

Centripetal is an adjective that describes any force or component of a force that points towards the centre of curvature of an object's path of motion. A centripetal force changes an object's direction without changing its speed. It is responsible for keeping an object moving in a circle. There is no special symbol for a centripetal force – **never write F_c, anywhere**! Your textbook does use this symbol, but it is a faulty habit – don't! Centripetal is simply an additional label for already familiar forces (F_t, F_g, F_n, etc.) and is a helpful term when discussing circular motion.

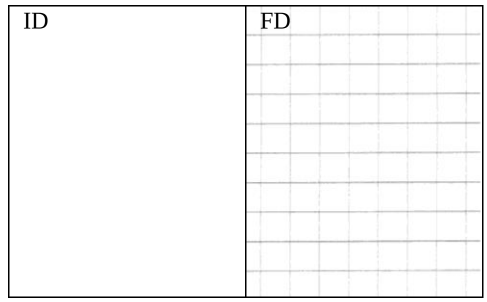
7. **Reason.** Which forces in the examples we have studied so far have acted as centripetal forces?

SPH4U Homework: Going in Circles Name:

A: Turning a Corner

1. **Reason.** Marie says, "When we turn the corner in a car, there must be an outwards force that pushes you across the seat and presses you against the door. That's what I feel." Emmy says, "I don't think so. I think it has to do with the frame of reference." Who do you agree with? Explain.

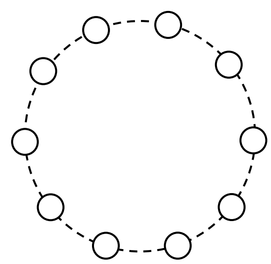
2. **Reason.** A car turns a corner. Draw an ID and FD for the system of the car. Which force acts as the centripetal force in this situation?



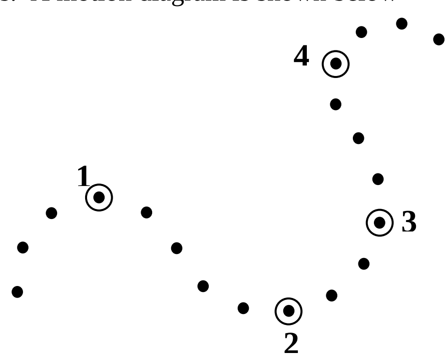
3. **Reason.** Isaac says, "I don't see how friction could be the centripetal force in this situation. It just doesn't seem right." Explain to Isaac what would happen to the car when it reached the corner and there was no friction interaction. What force is responsible for keeping the car moving in a circle?

4. **Reason.** When we investigated frames of reference a few classes ago, we decided that when we accelerate, we feel as if we are being pressed in the opposite direction. Is that conclusion valid for circular motion as well? Explain.

5. **Reason**. Use your new force rule to explain how to cause a hover puck to move in a circle simply by using gentle taps from a metre stick (no string!) Illustrate the force of your taps in the diagram.



6. **Reason.** The hover puck moves in a very mysterious manner due to unknown forces. A motion diagram is shown below with dots produced after equal intervals of time. Draw a vector that represents the centripetal force at the four moments in time indicated. Can you guess which net force is greater? Offer a rationale for your answer (our next lesson will help us clearly decide which is greater).



SPH4U: Radial Acceleration

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

What is special about the motion of an object moving in a circle? Only vectors will tell!

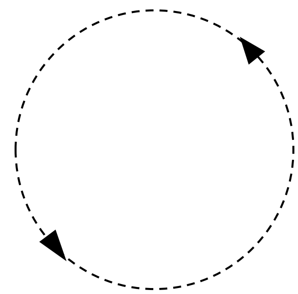
A: Instantaneous Velocity and a Curving Path

Attach a piece of string to a hover puck and swing it in a circle at a stready rate.

When we discuss circular motion, there are two important directions: (1) the *radial direction* which points inwards and outwards to the centre of curvature of the object's path, and (2) the *tangential direction* which points forwards or backwards, tangent to the object's curving path.

1. **Observe.** Release the string when the puck is in the 12 o'clock position. In what direction does the puck travel relative to the circle?

To draw an instantaneous velocity vector, identify the desired moment in time by drawing a point along the object's path. Draw the vector with its tail starting at that point. The vector arrow should be **tangent** to the object's path at that point.

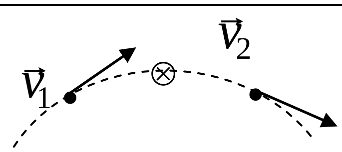


2. **Represent.** Draw an instantaneous velocity vector for the hover puck at four moments in time (at 3, 6, 9, and 12 o'clock).

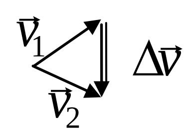
3. **Explain.** How do the four velocity vectors you drew compare?

B: Velocity Vector Diagrams

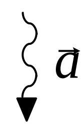
To find the radial acceleration of an object moving in circular motion, we will use a velocity vector diagram and learn a trick for choosing the two velocity vectors.



We want to estimate the acceleration for an object when it passes the middle point (⊗). Draw the initial velocity vector (v_1) a small time interval before the point. Draw the final velocity vector (v_2) an equal time interval after the point.



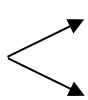
Redraw the two velocity vectors tail to tail. Draw the change in velocity vector going from the tip of v_1 to the tip of v_2.

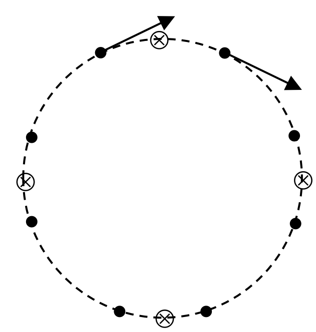


The acceleration, *a*, is in the same direction as the change in velocity, Δv, and has a magnitude $\Delta v/\Delta t$.

C: Acceleration and Circular Motion

1. **Represent.** An object moves at a constant speed in a circle. Use the vector subtraction technique to estimate the acceleration vector at the four moments shown in the diagram. **Neatly** show your vector work for each example (the first example is almost complete). Draw a wiggly acceleration vector inside the circle for each moment.



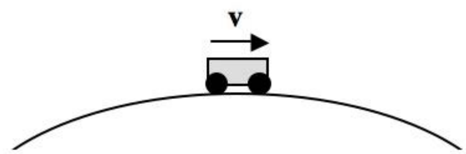


Adapted from *The Physics Active Learning Guide* by A. Van Heuvelen, Pearson, 2006

An object moving in a circle experiences an acceleration (a_r) in the radial direction pointing towards the centre of its circular path. This acceleration is called the **radial acceleration** (in the textbook this is called the centripetal acceleration).

2. **Reason.** How does the pattern for the acceleration vectors compare with the rule you developed for the net force in the previous investigation? What law of physics is this a result of?

3. **Represent.** A cart glides across the top of a low-friction, circular track. We will focus on the moment in time when the cart is at the highest point. Draw a velocity vector diagram to find the acceleration at that time. Draw an ID and FD, and explain how the diagrams agree according to Newton's 2nd law. Hint: at this moment, there are no important horizontal forces.



Velocity Vector Diagram	ID	FD	Agreement?

4. **Apply.** How would it *feel* if you were a passenger on the cart in this situation? Use the FD to help explain.

D: The Pendulum of Fate

In our classroom we have a 0.50 kg mass hanging on the end of a 1.0 m string. The string is connected to a spring scale.

1. **Predict.** The mass is at rest, hanging from the scale. Predict the spring scale reading. Justify your prediction.

2. Imagine you pull the mass to the side and release it such that it swings like a pendulum. Even though the mass does not move in a complete circle, this is still circular motion!
   (a) **Represent.** Apply your new understanding of circular motion when the mass is at its lowest point. Draw a velocity vector diagram and FD for the lowest point in the swing.

   (b) **Predict.** How will the spring scale reading as the mass swings past its lowest point compare with the reading when the mass was at rest? Explain.

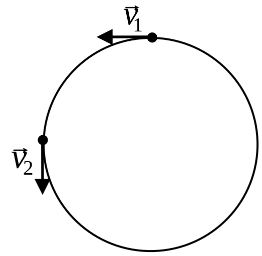
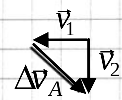
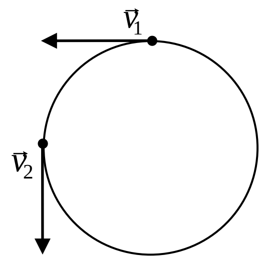
Velocity Vector Diagram	FD – Lowest Point

3. **Test.** Perform the experiment. Explain how the result agrees with our understanding of acceleration and force in circular motion.

E: Acceleration, Speed and Radius

Two identical physics buggies travel at a constant speed along two identical circular paths. Buggy A moves with a speed v and Buggy B with a speed $2v$. Buggy A completes a ¼ trip in a time Δt_A and experiences a change in velocity Δv_A.

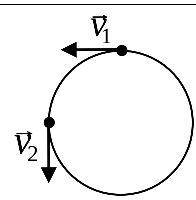
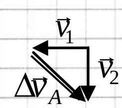
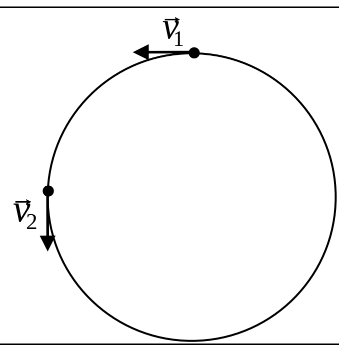
1. **Represent.** Use a velocity vector diagram to help compare the radial accelerations of the two buggies.

	Illustration	Velocity Vector Diagram	Time Interval	Acceleration
Buggy A			For a ¼ trip: Δt_A	$a_A = \frac{\Delta v_A}{\Delta t_A}$
Buggy B		How does Δv_B compare with Δv_A?	How does Δt_B compare with Δt_A?	Put it all together here: $a_B = \frac{\Delta v_B}{\Delta t_B}$ =

2. **Reason.** How would the acceleration change if the speed was tripled? (Be careful!)

Two identical buggies travel with the same constant speed along two circular paths with different radii. Buggy A moves in a circle of radius r and buggy B moves in a circle with radius $2r$. Buggy A completes a ¼ trip in a time Δt_A.

3. **Represent.** Use the vectors subtraction technique to compare the radial acceleration of each buggy.

	Illustration	Velocity Vector Diagram	Time Interval	Acceleration
Buggy A			For a ¼ trip: Δt_A	$a_A = \Delta v_A / \Delta t_A$
Buggy B				

4. **Reason.** How does the magnitude of the acceleration depend on the radius? (Use the word "proportional")

5. **Speculate.** We first figured out that the acceleration is proportional to the speed *squared* ($a \propto v^2$). In the second example, we saw that the acceleration is *inversely* proportional to the radius ($a \propto 1/r$). Combine these two results and create one equation for the magnitude of the radial acceleration during circular motion.

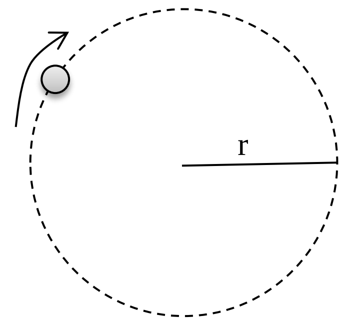
Equation for Radial Acceleration

**Check your result with your teacher **

When we analyze circular motion, it is often easiest to measure the frequency (f) or the period (T) of the circular motion rather than the speed. We can create two other handy equations for the radial acceleration using those quantities: $a_r = 4\pi^2 r f^2 = 4\pi^2 r/T^2$. Frequency is the number of rotations per second and is measured in hertz (Hz). Period is the time to complete one rotation.

F: Test the Acceleration Expression

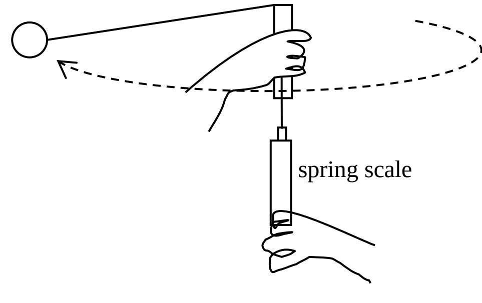
1. **Derive.** An object is moving in a circle with radius *r* and period *T*. Start with the equation for the radial acceleration you have just developed. Use your knowledge of circles (hint: perimeter and *T*) to create an expression for the speed of the object. Eliminate *v* from your acceleration equation and create the two other equations shown above.



2. **Predict.** According to our understanding of acceleration and net force, explain what happens to the magnitude of the centripetal force if an object spins faster with the same radius.

3. **Predict.** Explain what happens to the magnitude of the centripetal force if the object spins with the same **frequency** and the radius increases.

4. **Test.** Find the circular motion kit: a small tube, string (at least 1 m), rubber stopper, and spring scale (5 N). Attach the string to the stopper and thread it through the tube. Have one person hold the tube and another person hold a spring scale connected to the bottom of the string. Find some space where you can swing the stopper in a horizontal circle in the air above your heads. Don't hit people! Practice swinging it at a steady rate.



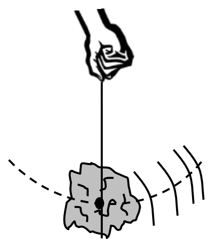
5. **Test and Evaluate.** Test your two predictions above. Note that keeping the same frequency is quite tricky! Were your predictions consistent with the observations? Do the new equations work?

SPH4U: Applying Circular Motion Ideas

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

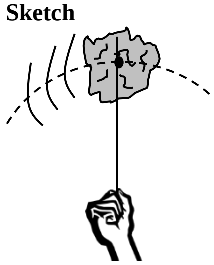
A: The Balancing Act?

Marie swings a rock in a vertical circle at a constant speed. The rock reaches the lowest point in its trip. Emmy says, "I can feel the string pulling down on my hand. There must be a net force downwards." Isaac says, "I think at the bottom the forces balance." Albert says, "Since the object is moving to the left at this moment, the net force must be to the left." Do you agree with anyone? Explain.

Sketch	**ID**	**Velocity Vectors**	**FD - bottom**	**Explanation**
				

B: Changing Tension?

Now Emmy swings the rock in a vertical circle at a steady rate. Marie says, "I can feel that the tension in the rope is different when the rock is at the top compared with at the bottom of its trip. I guess the force of tension is changing." Emmy says, "No, the force of tension can't be changing since the speed and acceleration of the rock is constant." Who do you agree with? Explain.

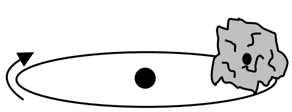
Sketch	**FD – top**	**FD - bottom**	**Explanation**
			

***Note – did you draw your F_g the same size in all your FDs*

Test. Swing a ball in a vertical circle and verify whether you can feel the changing tension force.

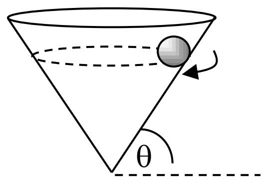
C: Rocks at 33½

Albert places a rock on a rotating platform, just like an old fashioned record turntable. It does not slip on the platform surface. Albert says, "At this moment in time the instantaneous velocity of the rock is forwards (out of the page), from this point of view, so friction will act in the opposite direction, into the page." Marie says, "I'm not sure. Since the rock is moving in a circle, I think the force of friction must act towards the centre." Who do you agree with? Explain.

Side view	**ID**	**FD (side view)**	**Explanation**
			

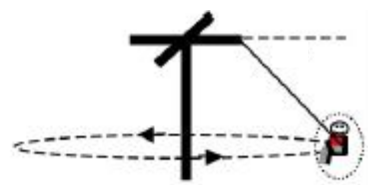
D: The Ball and the Funnel

Albert is visiting the Ontario Science Centre and sees an exhibit where a marble rolling in a funnel glides around in horizontal circles with no noticeable vertical motion (friction is negligible). Isaac says, “That is so cool!” Albert says, “But I don’t understand–shouldn’t gravity pull it down to the bottom pretty quick? I don’t see how it could travel in a circle.” Explain to Albert how this is possible.

Sketch	**ID**	**Newton’s 2nd Law** (line up your coordinate system with **the acceleration**!)	**Explanation**
	**FD**		

E: Evaluate the Problem

Identify the errors in the solution to the following problem. Provide a corrected solution.

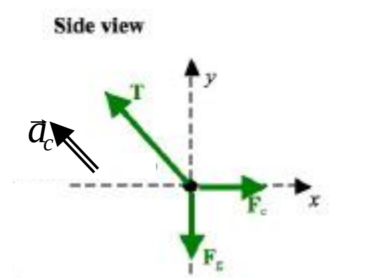


Problem: 80-kg Samuel rides at a constant 6.0-m/s speed in a horizontal 6.0-m radius circle in a seat at the end of a cable. Determine the size of the tension force in the cable when it makes a 58.5° angle with the horizontal.

Proposed Solution:

$F_t = m(v^2/r)$
$= (80\text{ kg})(6.0\text{ m/s})^2/(6.0\text{ m})$
$= 480\text{ N}$

The tension is 480 N.



F: Design a Problem

You are given the second last step in a problem where quantities have been substituted in an equation. Your task is to reverse engineer the problem from this step. Draw a sketch, a force diagram and describe the situation just like a textbook problem!

Sketch	**FD**	**Description**	
			$200\text{ N} + (50\text{ kg})(9.8\text{ N/kg}) = (50\text{ kg})v^2 / (12\text{ m})$

SPH4U: Universal Gravitation

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
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Good old Sir Isaac Newton created an equation to predict the size of the force of gravity between two masses (m_1 and m_2) that have a separation between their centres of (r):

$$F_g = \frac{Gm_1m_2}{r^2}$$

Where $G = 6.67 \times 10^{-11}$ Nm^2/kg^2 is the constant of universal gravitation, which describes the strength of the force of gravity.

A: Your Friend the Astronaut

Your friend, who is now an astronaut (m_A = 100 kg), is currently standing on the Earth ($m_E = 5.98 \times 10^{24}$ kg, $r_E = 6.38 \times 10^6$ m).

1. **Represent.** Your astronaut friend jumps into the air. Draw a sketch of your friend and Earth during the jump. Label the quantity, r. Draw an ID and a FD for your friend and Earth.

Sketch	ID	Astronaut FD	Earth FD

2. **Calculate.** Use the new equation for universal gravitation to find an algebraic expression for the ratio of force per unit of mass for the astronaut (F_g / m_A). Substitute the appropriate values into your expression and evaluate it.

3. **Interpret.** The ratio F_g / m_A tells us something important about the effects of gravity. Describe the meaning of this result.

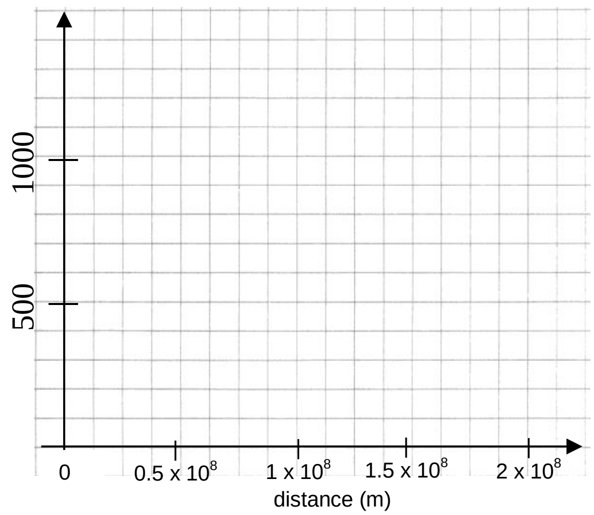
4. **Reason.** In your FDs you identified two forces of gravity. Compare the size and direction of these two forces.

5. **Reason.** Isaac says: "I understand from my third law that the astronaut exerts an upwards force on the earth, but this just seems strange. How come we never notice this upwards force?" Explain to Isaac.

6. **Explain.** Calculate the size of the force of gravity the earth exerts on the astronaut and the force the astronaut exerts on the earth using the expression for universal gravitation. Even if you never heard of Newton's Third Law, why is it not necessary to perform two separate calculations?

7. **Calculate.** Your friend blasts off and travels away from the earth. Complete the table showing the size of the force of gravity due to the earth on the astronaut at different distances from the centre of the earth. Plot a graph of F_g vs. r

Location	Distance	F_g
Earth's Surface	6.38×10^6 m (0.0638×10^8 m)	
International Space Station	6.39×10^6 m (0.0639×10^8 m)	
Cell Phone Satellite	4.22×10^7 m (0.42×10^8 m)	
Lunar Transfer Orbit	2.17×10^8 m	
Moon's Orbit	3.85×10^8 m	



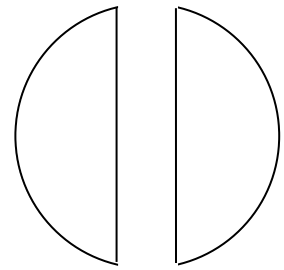
8. **Find a pattern.** Describe in words how the size of the force of gravity varies with the separation of the objects.

9. **Reason.** How far does Earth's gravitational force extend into the universe? Explain.

10. **Reason.** Anything with mass will interact gravitationally with anything else that has mass. This means there is a gravitational interaction between you and the person sitting beside you. Why don't we notice this interaction? Use a sample calculation to support your reasoning.

When we work with the law of universal gravitation, we will usually assume that the mass of the interacting object (like the earth) is concentrated in a single point. This assumption is valid so long as we don't enter the interacting object!

11. **Crazy Guess.** Imagine a hole is dug straight through the centre of the Earth. Describe your motion if you were to fall in. Ignore any air resistance! Don't spend to long on this question.



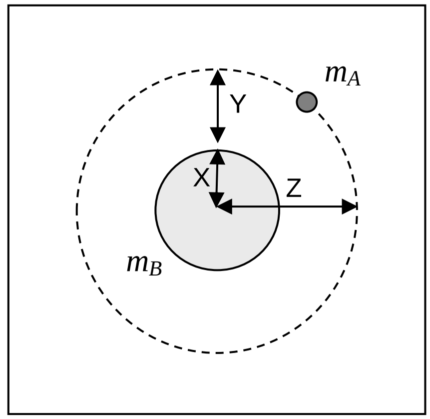
SPH4U: Orbits

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

Consider an object (m_o) like a satellite or a moon travelling in a circular orbit around the earth.

m_E = 5.98x10^{24} kg
r_E = 6.38 x 10^{6} m
G = 6.67x10^{-11} Nm^2/kg^2

1. **Represent.** Label the altitude (*h*), the radius of the circular orbit (r_o), the radius of Earth (r_E), matching them with the letters X, Y, and Z.



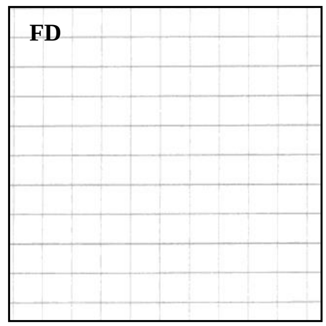
2. **Reason.** Which quantity, X, Y, or Z, does *r* in the expression for universal gravitation represent? Explain.

$$F_g = \frac{Gm_1m_2}{r^2}$$

3. **Reason.** Which quantity, X, Y, or Z, does *r* in the expression for the centripetal acceleration represent? Explain.

$$a_r = \frac{4\pi^2 r}{T^2}$$

4. **Represent.** Draw a force diagram for the object at the moment shown.



5. **Solve.** Start with Newton's 2nd Law. Then use universal gravitation and an expression for centripetal acceleration to create an equation that relates the radius of the orbit and the period of the orbit. Solve this for T^2. **Be careful with the labels for the masses!** (Don't memorize this equation.)

This result is known as **Kepler's law**, named after the brilliant mathematician who spent 25 years working out this result. How long did it take you? (Thanks, Newton!)

6. **Solve.** Complete the chart below which compares orbital velocities, altitude, radii and periods.

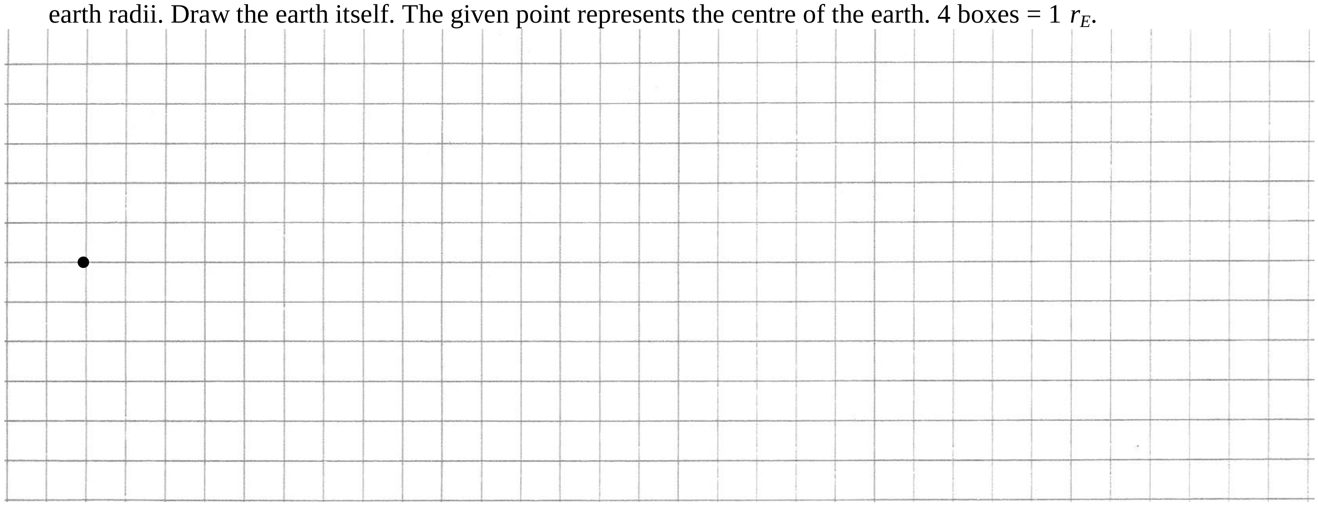
Location	Altitude	*r* (m)	# of Earth radii	*T* (s)
International Space Station	600 km			
Geostationary Orbit (satellite stationary above Earth's surface)				24 h =
Moon's Orbit				27 d =

Earth's Orbit around Sun (m_{sun} = 1.98 x 10^{30} kg)				

7. **Reason.** Albert says, “I understand that there still is gravity out in space, sometimes lots of it, but why do we see astronauts floating in the Space Shuttle when it is in orbit around the earth? They seem *weightless*.” Explain to Albert why. (Consult your chart from the previous investigation.)

8. **Reason.** Earth’s gravity is always pulling objects towards the centre of the earth. Why don’t objects in orbit fall straight down and crash into Earth?

9. **Represent.** Sketch and label a scale diagram of the radial distance of the first two orbits from question 6 in terms of earth radii. Draw the earth itself. The given point represents the centre of the earth. 4 boxes = 1 r_E.



10. **Represent.** Using this scale, where would the Moon be located? Find a golf ball and marble. Carefully position these to model the earth and moon. **Call your teacher over to check your set up**.

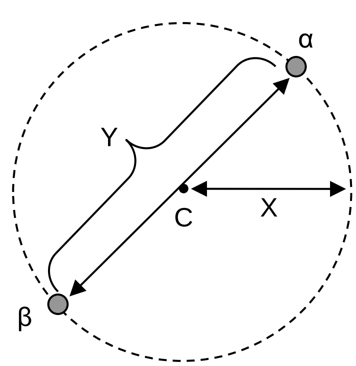
B: Twin Stars

When we model orbits in gr. 12 physics, we assume that the mass of the central object is so much greater than the mass of the orbiting object that the central object does not move. But this is not always the case! Consider a binary star system (*YM alpha* and *YM beta*) consisting of two equally massive stars which orbit one another.

1. **Reason.** How do you decide which star will orbit around which? Explain.

2. **Represent.** Label the radius of the orbit (r_o) and the separation between the centres of mass of each star (d), matching them with the letters X (radius) or Y (diameter). C is the common centre around which both stars orbit.

3. **Represent.** Use Newton’s 2nd law to write a complete expression relating the period and radius for the stars’ orbits. Be sure to use the given symbols!



SPH4U: "Oomph"

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

When you catch a heavy object you feel a lot of "Oomph". What is this mysterious quantity that we all kind of know? Let's find out.

A: Figuring Out the Formula for Oomph!

The more oomph something has, the harder it is to stop, and the more ability it has to knock other things over. Let's figure out the formula for oomph.

1. **Reason.** A small pebble and a large rock are thrown at the same speed.
   (a) Which one has more oomph? Why?

   (b) The rock is twice as massive as the pebble. Intuitively, how does the size of the rock's oomph compare with the pebble's oomph?

2. **Reason.** Picture two identical bowling balls, one of which is rolling faster than the other.
   (a) Which ball, the faster or slower one, has more oomph? Why?

   (b) The faster ball is exactly 7 times as fast as the slower one. Intuitively, how does the faster ball's oomph compare to the slower ball's oomph?

3. **Find a Relationship.** The physics concept corresponding to oomph is momentum. Building on your above answers, create a provisional definition (an equation) for momentum (oomph) in terms of mass and speed. Explain how the formula expresses your intuitions from questions 1 and 2 above. (For curious historical reasons, physicists use the letter *p* for momentum.).

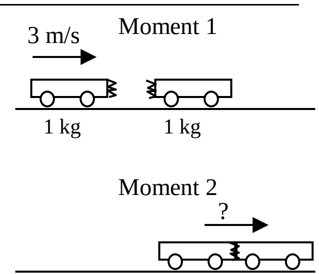
Provisional Definition of Momentum

p =

** *check with your teacher at this point* **

B: Testing Our Momentous Intuition

You will need a dynamics track and two carts. In the previous section, your intuitions about *oomph* led to a formula for momentum. Now let's see if this formula works for collisions. Cart A (1 kg) is rolling with negligible friction at 3 m/s and collides with and **sticks** with Velcro to cart B (identical to cart A).



1. **Predict.** Don't test it yet! Without writing any math, use your provisional definition of momentum to predict the speed of the carts at moment 2. Explain.

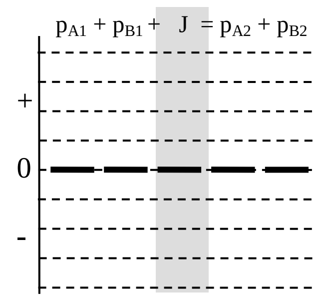
C. Meyer, 2017, adapted from University of Maryland Physics Education Research Group, Fall 2004

2. **Test.** Use the carts and dynamics track to test your prediction. Roughly speaking, do your observations agree with your prediction?

3. **Reason.** Did the momentum of the first cart change? What about the second cart? Did the **system total** of momentum for the **two carts** change?

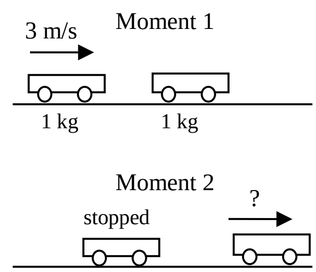
To help represent the momenta of a system at two moments in time we construct an *impulse-momentum bar chart*. In our notation, we use letters to denote different objects and numbers to indicate different moments in time. We draw a bar that represents the size and direction of the momentum of each object in the system. The exact heights are not important, but the bars must clearly show the correct ideas. The change in the momentum of the system is called the *impulse* and is represented by the symbol *J*.

4. **Represent and Explain.** Complete the momentum-impulse bar chart for the system of the two carts before and after the collision described above. For convenience, you can think of the cart A as having 3×1 = 3 units of momentum. Once complete, explain two ways in which the graph visually represents the fact that the impulse on the system was zero.

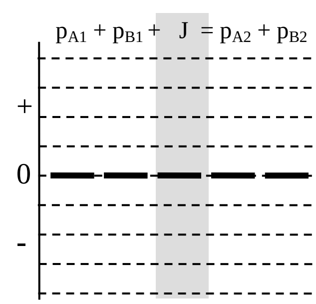


Here is another situation to consider: in a similar experiment, cart A collides with cart B magnetically. The two carts don't actually touch – the magnets act like a perfect spring between the two carts. After the collision, cart A is at rest.

5. **Predict.** Again without much math, predict the post-collision speed of cart B. Explain.

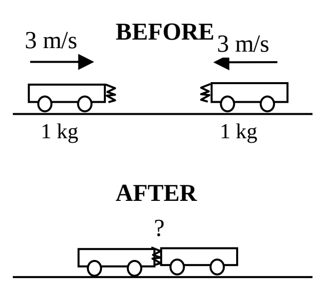


6. **Test.** Use the carts and dynamics track to test your prediction. Roughly speaking, do your observations agree with your prediction? Explain.

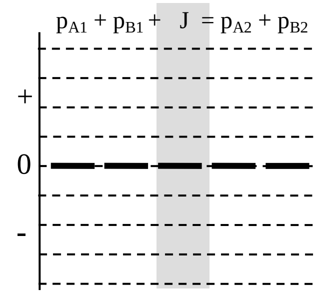


Here is one last situation to try out. The two carts are initially moving at 3 m/s in opposite directions. They collide and stick using Velcro.

7. **Predict and Test.** Intuitively, after the collision, how fast do the carts move and in what direction? Test your prediction.



8. **Represent.** Complete a momentum-impulse bar chart for this collision. Explain how the idea of direction is visually represented in the chart.



9. **Reason.** Does momentum "care about direction"? Explain and modify your provisional definition of momentum.

Official Definition of Momentum:

*** check with your teacher ***

C: The Conservation of Momentum

When we study the momentum of a system, we can construct an **impulse-momentum equation** to track the momentum of each system object and any transfer of momentum in or out of the system.

Idea: initial system total of momentum + momentum transfer in/out = final system total of momentum

Sample impulse-momentum equation: $m_A\vec{v}_{A1} + m_B\vec{v}_{B1} + \vec{J} = m_A\vec{v}_{A2} + m_B\vec{v}_{B2}$

When we use impulse-momentum equation, we almost always focus on the momentum in one particular direction. As a result, we write a component equation for the momentum and leave out the vector arrow symbols. We also leave out any terms that we know are equal to zero. We use positive or negative velocity values to indicate direction.

Problem. Let's practice using momentum conservation. A cart A (500 g) moves east at 0.5 m/s and collides with a cart B (1000 g) that is at rest. The carts bounce magnetically off each other. After the bounce, the cart B is moving east at 0.333 m/s.

1. **Represent.** A good, first step in any problem is sketching the initial and final states. Complete Part A below.

A: Pictorial Representation

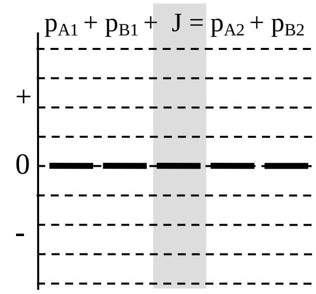
Sketch showing "before" and "after", coordinate system, label givens and unknowns with symbols, conversions, ~~describe events~~

① the collision begins

② the collision ends

2. **Reason.** Are there any important interactions between the system objects and the external environment? Will these affect the momentum of any system objects during the interval of time we are interested in? Explain.

3. **Represent.** Complete the momentum bar chart for the collision.



4. **Predict.** Without doing calculations, make a quick guess for the direction of the velocity of cart A after the collision. Explain.

5. **Calculate and Evaluate**. Now calculate cart A's velocity after the collision. Evaluate your prediction.

D: Mathematical Representation

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

E: Evaluation

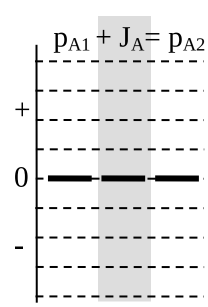
Answer has reasonable size, direction and units? Why?

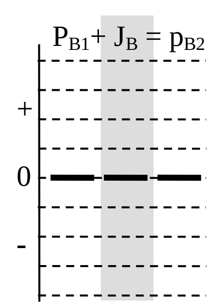
6. **Test.** Try out this collision on the track at the front of the class. Does the result agree with your prediction?

D: A Further Look - Impulse

1. **Represent.** Let's explore the collision in Part C above using the idea of impulse. Complete a bar chart with **cart A alone** as the system. Complete a bar chart with **cart B alone** as the system.

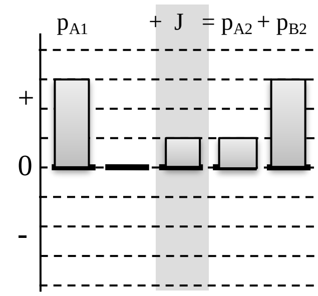
2. **Explain.** What does each bar chart tells us about the impulse (that is, the change in momentum) experienced by the individual carts?



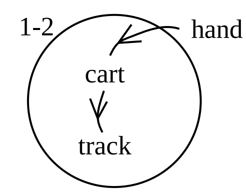


SPH4U: Energy and Momentum Unit Rubrics

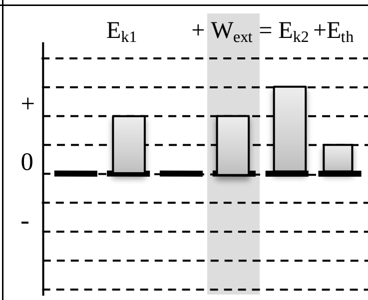
Momentum Bar Charts

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Bar chart is constructed but contains many errors or a major error: • Missing or extra bars • Bar chart math does not work out (Initial + change = final)	Momentum bar chart contains no major errors, but might have a few minor errors.	• Momentum bars are labeled with numbers for moments in time and letters for objects (“p_{A1}”) • Labels for the bars form an impulse-momentum equation. • Bars reflect a reasonable estimation of the mass and velocities of the objects • Bars show correct direction for momenta • Bars show the important differences or changes in momentum	

Energy Flow Diagrams

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Energy flow diagram is constructed but contains many errors or a major error: • Missing or extra energy flow lines • Inappropriate objects in system or environment	Energy flow diagram contains no major errors, but might have a few minor errors.	• Event numbers show the initial and final moments in time that are being compared • Each interaction involved in a flow of energy is represented by a single line with an arrow head • Only objects names are written and only objects that are involved in an energy flow are shown • Energy flow diagram shows the same transfers as the energy bar chart.	 (agrees with work-energy bar chart below)

Work-Energy Bar Chart

An attempt (1-2)	Needs some improvement (3-4)	Acceptable (5)	Exemplar = 5/5
Work-energy bar chart is constructed but contains many errors or a major error: • Missing or extra bars • Bar chart math does not work out (Initial + change = final)	Work-energy bar chart contains no major errors, but might have a few minor errors.	• Energy bars are labeled with numbers for moments in time and letters for energy label (“E_{k1}”) • Labels for the bars form a work-energy equation. • Bars reflect a reasonable estimation of the quantities • Bars show correct sign for energies • Bars show the important differences or changes in energy • Bar chart shows the same energy transfers as the energy flow diagram	 (agrees with energy flow diagram above)

SPH4U: The Idea of Conservation

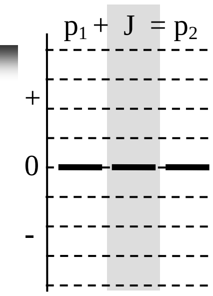
Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

There are some situations where momentum seems to appear or disappear. Let's study one of these situations carefully.

A: The Slowing Block

A 1.0 kg block is initially moving at +1.5 m/s and sliding along a table. It comes to a stop.

1. **Represent.** Complete a momentum-impulse chart for the system of the block. How much momentum did the system lose?



2. **Reason.** Are there any important interactions between the system (the block) and the external environment? How does this help to explain the system's loss of momentum?

The Momentum Conservation Condition: The total momentum of a system remains constant when the net force the system experiences is zero. The total momentum of a system *can* change if the system experiences a net force from its environment (objects outside the system). This change, also known as the *impulse*, is related to the net force and the amount of time the force acts: $\Delta \vec{p}_{system} = \vec{J} = \vec{F}_{net}\Delta t$. When F_{net} = 0 (or J = 0) the system's momentum is remains constant. Use this as the criteria to decide whether to use momentum to solve a problem.

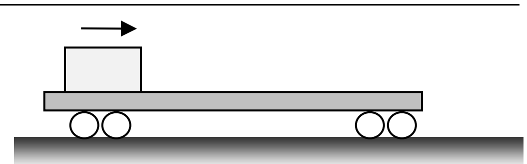
3. **Represent**. Draw an ID and FD for the system of the block.

4. **Speculate.** Consider the force responsible for slowing the block. What is the other force in a 3rd law pair with that force? Use that other force to help you guess where the block's momentum went. Make a guess and move on!

ID	FD

B: The Block on a Track

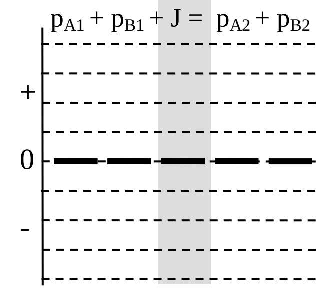
The block is moving at 1.5 m/s, just like before, and is gently lowered on to a level track that is supported on wheels and is free to move (no friction). The track has a mass of 2.3 kg and is initially at rest.



1. **Predict.** What will happen after the block is released?

2. **Test and Observe.** Use the equipment at the front of the class to test your prediction and speculation. Describe how your observations help to confirm or disprove them.

3. **Represent and Reason.** Complete a momentum-impulse bar chart for the block-track system. What is the net force on the block-track system? Explain.

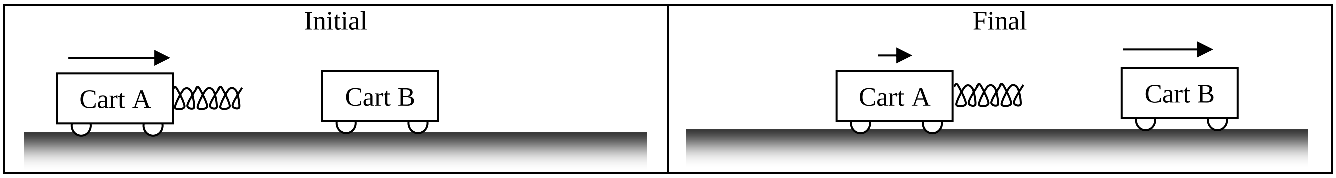


4. **Calculate.** Write an impulse-momentum equation. Find the final velocity of the track.

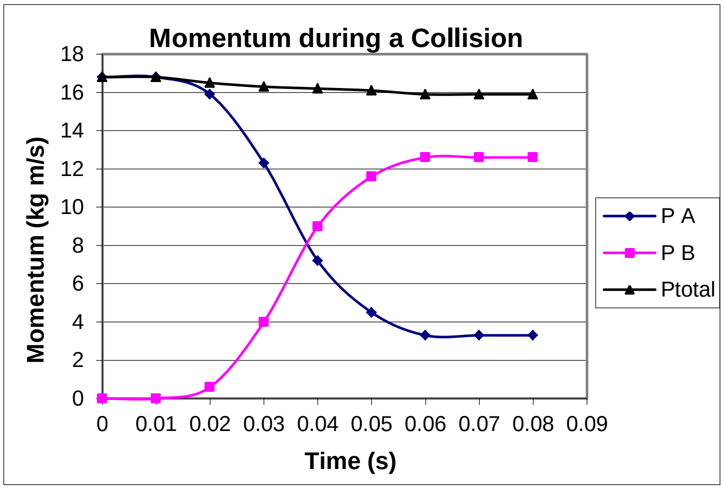
5. **Reason.** Imagine the mass of the track was increased enormously to equal that of the earth. Describe what would be different. How does this relate to the situation of part A?

C: The Process of a Collision

Collisions often occur very quickly and we don't usually notice what is actually happening **during** a collision. In this example, cart A (1.0 kg) collided with a smaller cart B (0.5 kg) using an uncompressed spring. The velocity of each cart was recorded at 9 moments in time and used to calculate the momentum and kinetic energy. A third line on each graph represents the total momentum and total kinetic energy of the **system of two carts**.



1. **Represent.** Draw a vertical line on the graph labelled "A" to indicate the moment in time when the collision begins and one labelled "B" to indicate when the collision ends. What is the duration of the collision?



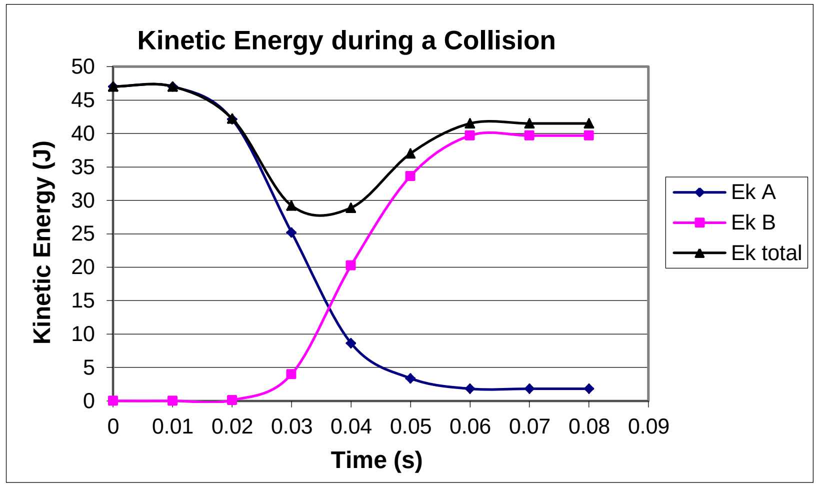
2. **Reason.** What happens to the spring at moments "A" and "B"?

3. **Find a Pattern.**
   (a) Use the momentum graph to find the impulse experienced by **each cart** during the collision.
   (b) Use the impulse to calculate the net force for each cart.
   (c) What law of physics relates the values of the two carts (disregard the small variations due to friction)?

	Cart A	Cart B
Impulse		
F_{net}		

The Idea of Conservation: A conserved quantity is one whose total for a system remains the same at *every* moment in time, so long as the quantity does not enter or leave the system. A quantity is *not* conserved if it "disappears" or changes into something else.

4. **Reason.** Carefully study the graphs showing the total momentum and total kinetic energy of the system. Ignoring the small losses due to friction, which of these quantities is a conserved quantity? Explain.



5. **Reason.** Notice how the total kinetic energy dips down during the collision. This indicates a transfer of energy. Where has the energy been transferred?

6. **Represent.** Draw a vertical line on the kinetic energy graph labelled "C" to indicate the moment in time when the spring was at its maximum compression. Approximately how much energy was stored in the spring at this moment?

D: The Buggy Challenge

1. **Predict.** Your teacher will turn on a physics buggy, gently lower it on to the sliding track used earlier today, and release it. The mass of the buggy is less than the track. How will the buggy and track move? Use appropriate physics diagrams to support your prediction.

SPH4U: Types of Collisions

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

A collision may roughly fall in to three categories based on how the system's total kinetic energy ($E_k = ½mv^2$) before and after the collision compares. If the total kinetic energy decreases due to the collision, it is called an *inelastic* collision. If the total kinetic energy remains is the same, the collision is called *elastic*. If the total kinetic energy increases, the collision is called *superelastic*. Our goal today is to study collisions that fall in to these three categories.

You need a dynamics track and two carts. We will not be making precise measurements. We will simply estimate speeds or changes in speeds and try to making some decisions based on that. **Make sure that carts don't hit the floor! Turn them upside-down when you are not using them! Place obstacles at the ends of the track!**

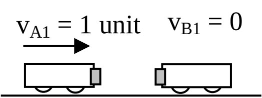
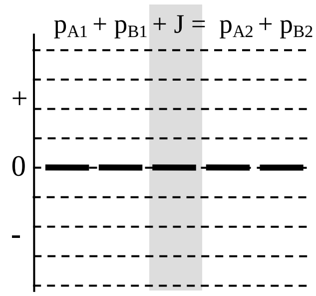
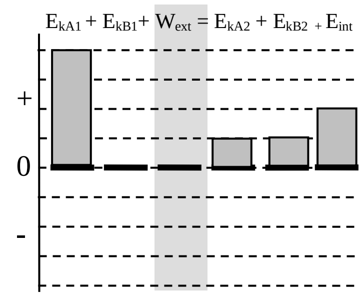
A: The "Sticky" Collision

1. **Observe and Represent.** For the collision below, sketch the before and after situations.

2. **Reason.** Is the total momentum of the system constant during this collision? Explain.

3. **Represent.** Complete a momentum-impulse bar chart for the two cart system. Use your understanding of momentum conservation to help estimate the velocities just before or after the collision (for example, v_{A1} = 1 unit).

Situation: Sticky **Type of Collision**:

Before - Moment 1	After - Moment 2	Momentum Bar Chart	Energy Bar Chart
			

A *work-energy* bar chart shows the amount of energy stored in different mechanisms of a system (motion, gravitational field, etc.) at two moments in time. The W_{net} column represents the flow of energy in or out of the system due to external forces, also known as the external work. A new column has been included to account for the *internal energy:* energy stored in other mechanisms of this system (for example heat, vibrations and many more). The heights of the bars in the graph do not need to be exact – we typically draw these charts before we make any calculations. What is important is that bars illustrate the correct ideas.

4. **Interpret.** What does this bar chart tell us about the amount of kinetic energy in the system before and after the collision? What about the total energy? Which quantity is conserved?

5. **Reason.** What type of collision is this an example of: *elastic, inelastic,* or *superelastic*? Record this above the chart.

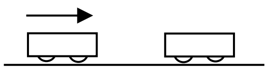
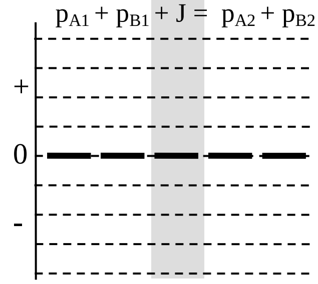
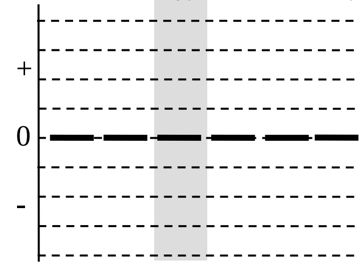
A sticky collision is not the only kind of inelastic collision. Technically, any collision that loses kinetic energy is an inelastic collision. A sticky collision is special because is results in the largest loss of kinetic energy when the objects move together as one (same velocity) after the collision. For this reason it is also called a *completely inelastic collision.*

6. **Represent.** Write an impulse-momentum equation for this system. Write a work-energy equation for this system. (Remember, you don't need to write any quantities that are zero).

B: The “Bouncy” Collision

1. **Represent and Reason.** For the magnetic collision below, sketch the before and after situations. Estimate the speeds involved. Complete a momentum-impulse bar chart and energy bar chart. Write the equations for the system. Does the system gain or lose kinetic energy? Decide what type of collision it is.

Situation: Bouncy **Type of Collision**:

Before - Moment 1	**After - Moment 2**	**Momentum Bar Chart**	**Energy Bar Chart**
		$p_{A1} + p_{B1} + J = p_{A2} + p_{B2}$ 	$E_{kA1} + E_{kB1} + W_{ext} = E_{kA2} + E_{kB2} + E_{int}$ 

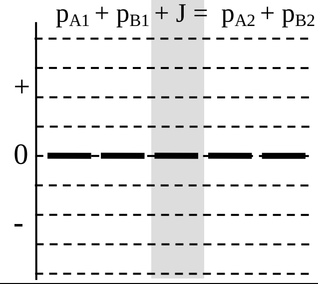
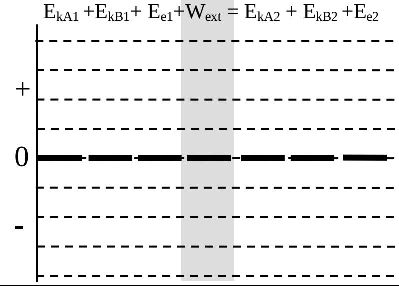
Impulse-momentum equation:

Work-energy equation:

C: The Explosion

1. **Represent and Reason.** Complete the chart below for the explosion. Note: the spring is part of the system.

Situation: Explosion **Type of Collision**:

Before - Moment 1	**After - Moment 2**	**Momentum-Impulse Bar Chart**	**Energy Bar Chart**
$v_{A1} = 0$ $v_{B1} = 0$  Compressed spring is released. Get ready to catch!		$p_{A1} + p_{B1} + J = p_{A2} + p_{B2}$ 	$E_{kA1} + E_{kB1} + E_{e1} + W_{ext} = E_{kA2} + E_{kB2} + E_{e2}$ 

Impulse-momentum equation:

Work-energy equation:

In this final example energy was stored in the spring (elastic energy, E_e). This could have been counted as another storage mechanism for internal energy, but since we will soon be able to measure and describe energy stored in springs carefully, we gave spring energy its own bar.

2. **Reason.** Isaac drew his bar chart for the previous example with E_{kA2} as a positive bar and E_{kB2} as an equal-sized positive bar. Albert drew E_{kB2} as an equal-sized negative bar. Who do you agree with? Explain.

3. **Reason**. Is energy a vector or scalar quantity? Use the bar charts you drew in this investigation to help explain.

4. **Explain**. For the completely inelastic collision, suppose we measured m_A, m_B, and v_{A1}. Algebraically solve for E_{int} in terms of E_{kA1} for the collsion.

SPH4U: 2-D Momentum Homework	Name:

A typical problem involving the conservation of momentum in 2-D is often challenging, but usually due to lack of organization and careless mistakes. Follow the solution format and these following suggestions carefully! Note that parts B and C have been omitted here, but continue to do them whenever you can.

Problem
Two hover pucks glide towards each other, collide and then glide away. Puck A (5.0 kg) was initially travelling at 2.0 m/s [E 25^o N]. Puck B (3.0 kg) was initially travelling at 4.0 m/s [E 30^o S]. After the collision, puck A travelled at 1.6 m/s [E 27^o S]. Determine the velocity of Puck B after the collision.

A: Pictorial Representation

Sketch showing "before" and "after", coordinate system, label given information, conversions, unknowns, key events

v_{A1x} =	v_{A1y} =
v_{B1x} =	v_{B1y} =
v_{A2x} =	v_{A2y} =
v_{B2x} =	v_{B2y} =

D: Mathematical Representation

Complete equations, describe steps, algebraic work, substitutions with units, final statement

(1) Use the conservation of momentum to find the *x*-component of the velocity of puck B after the collision:

$m_a v_{a1x}$ +

(2)

(3)

E: Evaluation

Answer has reasonable size, direction and units?

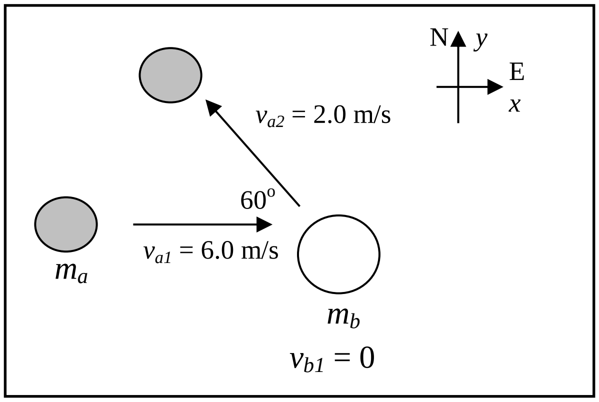
SPH4U: Momentum in 2-D

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

Momentum is a vector quantity and the Law of Conservation of Momentum is a vector equation. An object's momentum can be broken up into components and so can the law, meaning that momentum is conserved in each component direction.

A: The Collision

Consider an example where a small, fast moving hover puck (m_a = 2.0 kg) collides with a large stationary hover puck (m_b = 4.0 kg). Friction is small enough to be negligible.



v_{a1x} =	v_{a1y} =
v_{b1x} =	v_{b1y} =
v_{a2x} =	v_{a2y} =

1. **Predict.** Use your intuition to predict the direction m_b will travel after the collision. Draw a vector arrow in the diagram to show this. Briefly explain your reasoning. Do this quickly and move on!

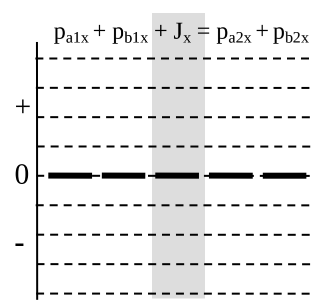
2. **Solve.** For simplicity, we choose a coordinate system that lines up with v_{a1}. Determine the *x*- and *y*-components of all the known velocities. Draw a component triangle when appropriate. Record the results in the table above. Indicate which components are unknown. Show your work and **be sure to use the sign convention**!

B: The *x*-momentum

1. **Solve.** Find the *x*-components of all the three momentum vectors we have velocities for. Show your work.

   p_{a1x} = p_{b1x} = p_{a2x} =

2. **Represent.** Draw a bar in the momentum bar chart for the three *x*-momenta you calculated above.



3. **Reason.** Does the system experience a net force from its environment? What does this imply about J_x?

4. **Predict.** Draw a bar in the chart representing the *x*-momentum of puck B after the collision. Explain your prediction by referring to the bars in your chart.

5. **Reason.** Isaac remarks that the magnitude of p_{b2x} is quite large compared with the other components. "It must be going really fast." Do you agree or disagree? Explain.

6. **Represent and Solve.** Use the bar chart to write an impulse-momentum equation for the *x*-direction. Solve for v_{b2x}.

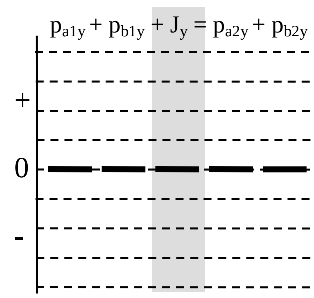
C: The *y*-momentum

1. **Solve.** Find the *y*-components of all the three momentum vectors we have velocities for. Show your work.

   p_{a1y} = p_{b1y} = p_{a2y} =

2. **Represent.** Draw a bar in the momentum bar chart for the three *y*-momenta you calculated above.

3. **Predict.** Draw a bar in the chart that represents the *y*-momentum of puck B after the collision. Explain your prediction by referring to the bars in your chart.



3. **Represent and Solve.** Use the bar chart to write an impulse-momentum equation for the *y*-direction. Solve for v_{b2y}.

4. **Reason.** Looking back at your work so far, why was it helpful to choose a coordinate system that lined up with v_{a1}?

D: The Final Result

1. **Solve**. Find the velocity $\vec{v}_{b2}$ (magnitude and direction). Be sure to draw the component triangle.

2. **Solve and Test.** Compare your velocity prediction with the simulation, if possible.

3. **Summarize.** What does it mean to say, "Momentum is conserved in two dimensions"?

SPH4U: 2-D Collisions

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

The collision on the next page has had the path of one object removed! Your challenge is to reconstruct the path. Examine the collision and read the details describing it, then follow the steps below.

1. **Observe.** Label the points where the collision appears to begin and end. Explain how you can tell.

2. **Reason.** Marie says, "Let's choose a coordinate system that lines up with the page – that will be the most helpful." Emmy says, "I think we should choose one that lines up with the initial velocity of puck A. That will be easiest." Who do you agree with? Explain.

3. **Observe and Reason.** Isaac says, "Let's use units of cm/s for our result – that will be convenient." Albert says, "Hmm … maybe we should use m/s, even though the numbers will be very small – they are S.I. units." Who do you agree with? Explain.

4. **Represent and Solve.** Write an impulse-momentum equation for the *x*-direction. Isolate v_{b2x} (the equation will simplify). Make the necessary measurements from the next page (show these) and record your results in the chart. Solve for v_{b2x}.

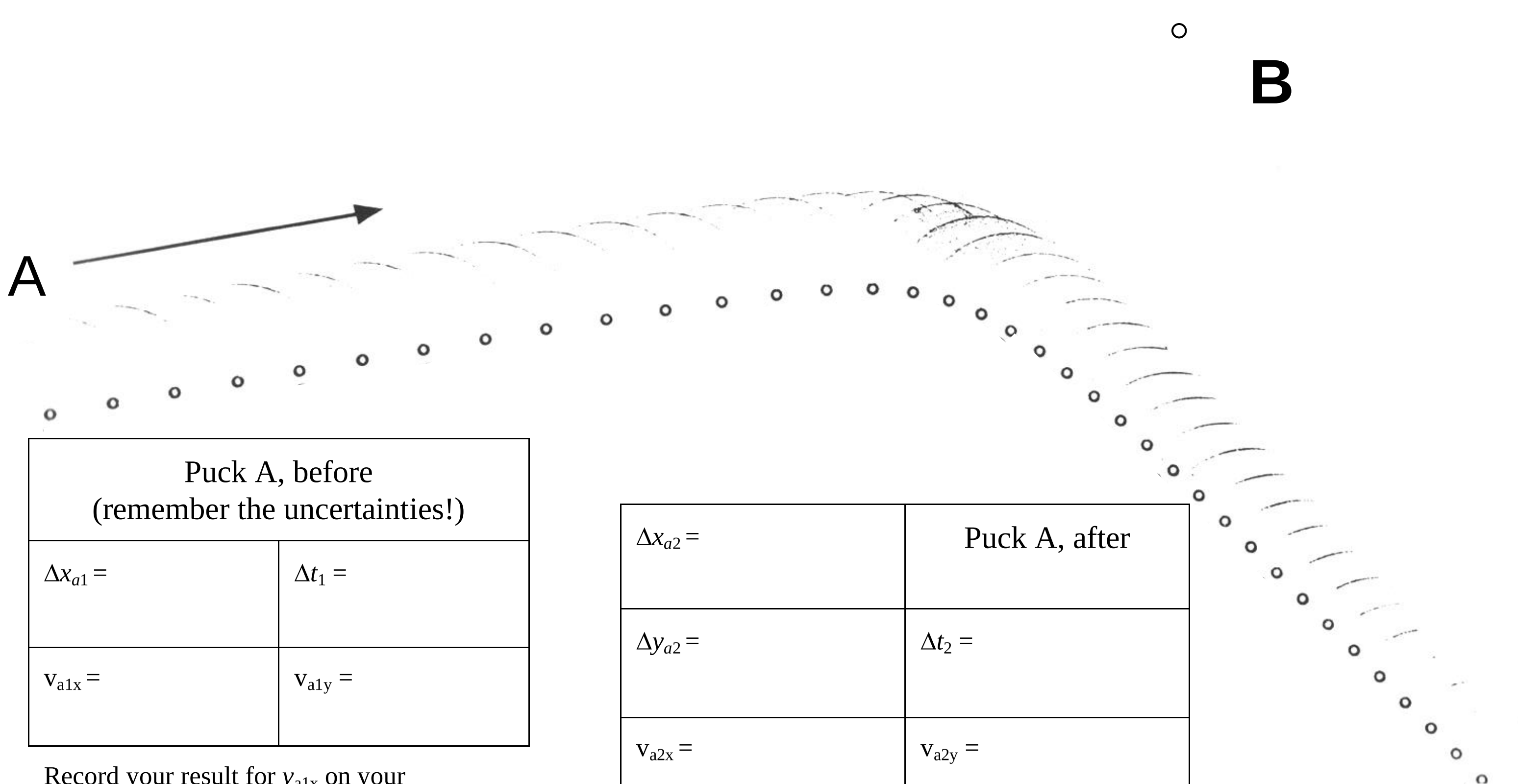
5. **Represent and Solve.** Write an impulse-momentum equation for the *y*-direction. Make the necessary measurements from the next page and record these in the chart. Solve for v_{b2y}.

6. **Calculate and Test.** Determine the vector $\vec{v}_{b2}$. Carefully draw the vector beginning at the circle near the "B" (If you have time, draw the circles too!)

   *** Check this with your teacher! ***

7. **Calculate and Reason.** Use kinetic energy calculations to help explain what type of collision this is.

On this page is pictured part of a collision between two dry-ice pucks A and B ($m_a = m_b = 300$ g). The collision takes place using magnets and is captured using a strobe light that flashes 10 times a second. The centre of each puck is indicated using a small circle and the path of puck B has been erased. Puck B was initially at rest and was positioned at the small circle near the letter B. Show your measurements and velocity calculations on this page.



Puck A, before (remember the uncertainties!)	
Δx_{a1} =	Δt_1 =
v_{a1x} =	v_{a1y} =

Record your result for v_{a1x} on your whiteboard using units of cm/s and with an estimated uncertainty.

Δx_{a2} =	Puck A, after
Δy_{a2} =	Δt_2 =
v_{a2x} =	v_{a2y} =

SPH4U: Work and Kinetic Energy

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

How can the energy of a particle change? When an external force acts on a particle while it moves through a displacement, energy flows into or out of the particle. This process is called work and the amount of work done (or energy that has flowed) due to the force can be found from the equation: $W = |F||\Delta d|\cos\theta$, where θ is the angle between the force and displacement vectors.

A: The Flow of Energy

Your teacher has a track with two carts set up. A large cart, cart A (1.0 kg) is moving right and a small cart, cart B (500 g) is at rest. They collide magnetically and travel on a frictionless track.

1. **Predict.** (*individually*). Describe how each cart will move after the collision.

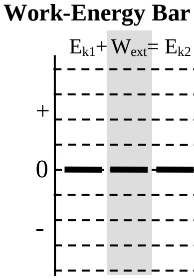
2. **Observe** (*as a class*). Describe the motion of each cart after the collision.

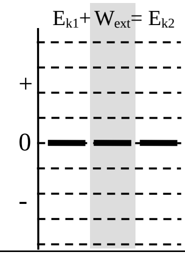
An *energy-flow diagram* is similar to an interaction diagram, but with two differences: we only draw the lines connecting objects if there is a flow of energy between them and if there is an energy flow, we add an arrow showing the direction of the flow. So keep in mind that an *interaction diagram* helps us construct a *force diagram*, while an *energy-flow diagram* helps us construct a *work-energy bar chart*.

3. **Reason.** Which object has gained energy? Which has lost energy? Is energy lost to the environment? How did you decide?

4. **Represent.** Draw an energy flow diagram for the system of the two carts.

5. **Represent.** Events 1 and 2 occur at the beginning and end of the collision. Follow the instructions and complete the chart below for the system of cart A and then for the system of cart B, each of which we imagine as a point particle.
   (a) Draw a vector arrow for the displacement of the cart and the force acting on the cart during the collision.
   (b) Complete a motion diagram for the cart between moments 1 and 2. Describe its motion: is the cart *speeding up, slowing down,* or *moving with a constant speed*?
   (c) What is happening to the energy of the system of the cart? Draw an energy flow diagram for the system of the cart.
   (d) According to the equation for work, is the work done by this force positive, negative or zero? Give a sample "calculation" for the sign including the angle θ.
   (e) Complete the work-energy bar chart for the system of the cart.

System = Cart A	**Displacement of cart**	**Motion Diagram**	**Energy-Flow Diagram**	**Work-Energy Bar Chart** 
Sign of Work	**Force of B on A**	**Description of Motion**		

System = Cart B	Displacement of cart	Motion Diagram	Energy-Flow Diagram	Work-Energy Bar Chart
Sign of Work	**Force of A on B**	**Description of Motion**		

6. **Reason.** We have been assuming (consciously or not) that the gravity and the normal force do not cause energy to flow into or out of the system. Use the equation for work to help explain why this was correct. (Hint: θ)

7. **Reason**. Does the result of the work equation depend on your choice of sign convention? Is work a scalar or vector quantity? Explain.

B: Work from Multiple Forces

1. **Represent.** In a new experiment, two hands push horizontally on the same cart. Hand 1 pushes to the left on the cart and Hand 2 pushes to the right. The cart is moving to the right and is now speeding up.
(a) Draw a motion diagram for the cart.
(b) Draw a complete force diagram for the system of the cart. Label the applied forces F_{a1} and F_{a2}.
(c) Decide whether the work done by each force is *positive, negative,* or *zero*. Indicate this by writing a +, –, or 0 along side the force vector.
(d) Draw an energy-flow diagram for the cart
(e) Is the net work on the system above positive, negative or zero? Why?

Motion Diagram	Force Diagram	Energy-Flow Diagram	Net Work

When a system has multiple interactions with its environment it may gain or lose energy due to a number of forces. The total change in energy of the system is the *net work*. The net work can be found in two different ways: by adding up the work from the individual forces or by finding the work due to the net force.

$$W_{net} = \Sigma W = W_1 + W_2 + \ldots \text{ or } W_{net} = |F_{net}||\Delta d|\cos\theta$$

A single particle that experiences a net force will accelerate and gain or lose kinetic energy. This idea is called the *net work - kinetic energy theorem,* $W_{net} = \Delta E_k$. This theorem is closely related to Newton's 2nd Law, but only applies to single particles.

2. **Represent**. Two hands continue to push on opposite ends of the cart, but with different magnitudes than before. The cart is moving to the left and is slowing down. Complete the chart below like in question #1 above.

Motion Diagram	Force Diagram	Energy-Flow Diagram	Net Work

3. **Summarize.** What is the physical significance of positive, negative and zero net work? What happens to a particle?

SPH4U: Gravitational Energy

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

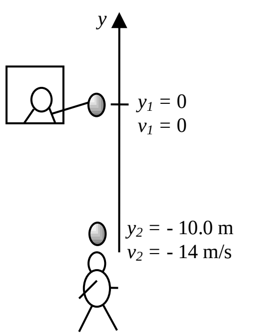
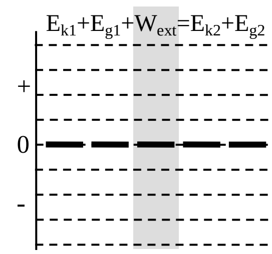
Energy can be stored in Earth's gravitational field by raising an object's vertical position. We label energy stored this way *gravitational* energy. When measuring gravitational energy, upwards is **always** the positive direction. The amount of energy stored is always measured relative to some vertical origin, $y = 0$, and can be found using the equation: $E_g = mgy$. Note: the value for g is **always** a positive quantity.

On a hot day, you look out a third story window and hold in your hands a 2.0 kg water balloon (a big one!). Your friend walks below the window, not noticing your balloon 10 meters above. You release the water balloon. We will analyze what happens next using different vertical origins.

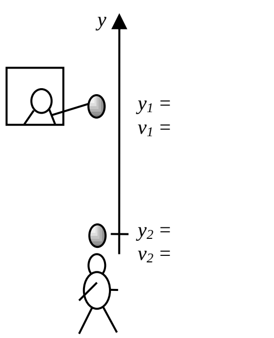
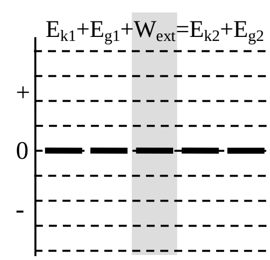
Flow

1. **Represent.** On a whiteboard, draw an energy flow diagram for the Earth-balloon system while the balloon falls.

2. **Represent and Calculate.** You set the vertical origin at your hand. Calculate the energies involved. Add up the total energies at each moment. Complete the work-energy bar chart for the earth-balloon system.

Sketch	Gravitational Energy	Kinetic Energy	Total Energy	Work-Energy Bar Chart
	E_{g1} = E_{g2} =	E_{k1} = E_{k2} =	E_{T1} = E_{T2} =	

3. **Represent and Calculate.** Now you set the vertical origin at your friend's head. Complete the given information for the sketch below. Calculate the energies involved. Add up the total energies at each moment. Complete the work-energy bar chart.

Sketch	Gravitational Energy	Kinetic Energy	Total Energy	Work-Energy Bar Chart
	E_{g1} = E_{g2} =	E_{k1} = E_{k2} =	E_{T1} = E_{T2} =	

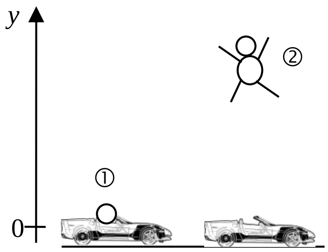
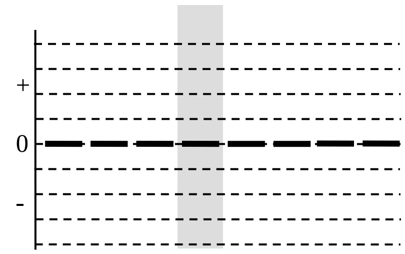
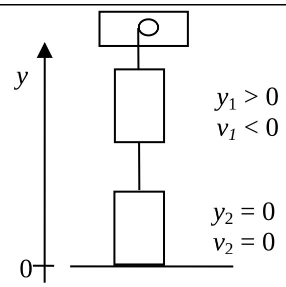
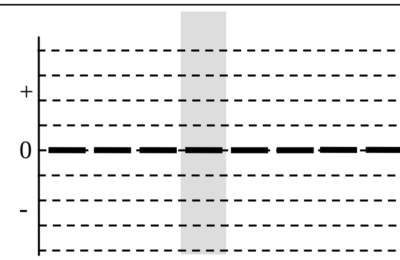
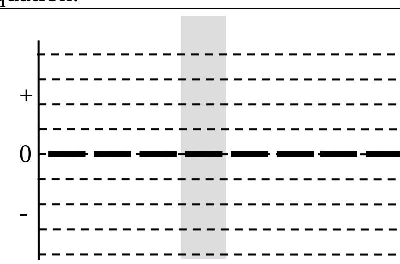
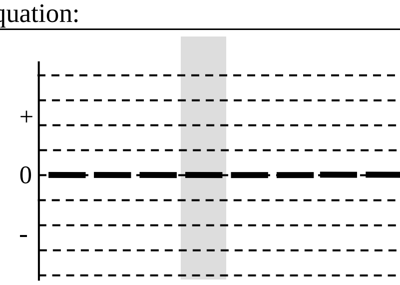
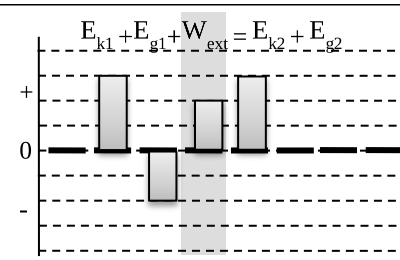
C: Thinking About Energy

1. **Explain.** Does the energy flow diagram agree with the two bar charts? Explain in detail.

Adapted from: Laws, P. *Workshop Physics Activity Guide. Module II.* John Wiley, 2004

SPH4U: Transfers of Energy Homework   Name:

1. **Represent.** Each row in the chart below gives multiple representations of one situation. Complete the missing parts for each row.

Word Description	Sketch Showing Events	Work-Energy Bar Char
(i) A stunt car has a spring-powered ejector seat. When the spring is released, the seat with its passenger is launched out of the car and reaches a maximum height y_2 above its starting position. (The elastic energy stored in the compression Δx of a spring is E_e) System: Earth, person, spring	 $y_1 = 0$ $v_1 = 5$ m/s $y_2 > 0$ $v_2 = 5$ m/s	 Equation:
(ii) An elevator is initially moving downwards at speed $v_{1.}$ It approaches the ground floor and slows to a stop in a distance *h*. System:		 Equation:
(iii) A cart is rolling down an inclined track. You use your hand to slow it down, but don't stop it. Friction is negligible. System:		 Equation:
(iv) A block is at rest at the bottom of an incline. You give it a large push. The block glides up the incline a short distance and stops on the incline due to friction. System:		 Equation:
(v) Describe your own situation:	Sketch the situation:	 Equation:

SPH4U: Transfers of Energy

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

Nobody really knows what energy is, but we do know how it behaves. Energy is a quantity that can be transferred between objects and that can be used to make predictions about future events. By carefully keeping track of where the energy is located, or stored, we can construct equations to help with our predictions.

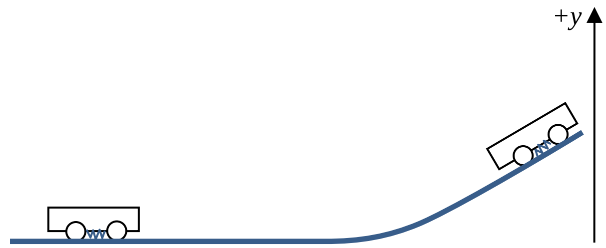
A: An Energetic Example

Your teacher has a ramp set up at the front of the class. A cart with a friction pad attached underneath glides down the incline, across a horizontal section, and collides with a bumper. Your challenge is to predict the impact speed of the cart when it hits the bumper.

1. **Represent.** Complete part A of our solution process. Hints: There are **two** important events in this situation. Indicate your vertical origin and label vertical positions for each event (see last lesson as an example).

A: Pictorial Representation

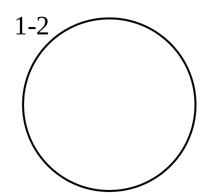
Sketch showing events, coordinate system, label givens & unknowns, conversions, describe events



2. **Reason.** Which objects interact with the cart? Which interactions involve a transfer of energy?

To understand the role of energy in a problem, we need to choose a system, or a collection of objects, whose energies we will track. We have a freedom to include **any** objects in our system and no matter our choice, we should always agree on the final answer. If an interaction can easily be described using energy (e.g. gravity), include those objects in your system. If an interaction is more easily described using work (e.g. applied, tension), make one object external. Friction effects involving transfers to thermal energy are best described as internal energy that is shared between system objects (they each get warmer). If this is the case, we will keep objects like the ground surface, roads, and tracks inside the system.

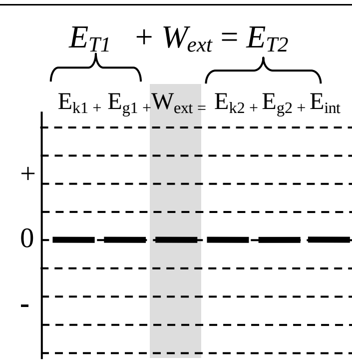
3. **Reason.** Based on the advice above, choose your system. Draw an energy-flow diagram for the system between events 1 and 2.



The law of the conservation of energy states that the total energy of a system remains constant unless energy flows into or out of the system. This flow of energy can be due to the work done by an external force. The total energy of the system and its changes may be expressed by a *work-energy equation*: $E_{T1} + W_{ext} = E_{T2}$.

4. **Represent.** Complete a work-energy bar chart for events 1 and 2.

5. **Represent.** The bar charts help you to write the work-energy equations for the system comparing the two moments in time. Do this using the same symbols as in the chart.



6. **Explain.** When you practice problems like this in your homework, part C asks for a word explanation. Let's practice: describe the motion of the cart and use energy transfers into/out of/within the system to explain why it moves the way it does.

To find the amount of thermal energy (which we are calling E_{int}) due to the sliding block, we need to use the definition of work to create a simplified equation. $W = |F||\Delta d|\cos\theta$. When an object is sliding, the angle between F_f and Δd is 180^o. This gives $W = -F_f \Delta d$. The amount of thermal energy should be a positive number so we create the equation: $E_{th} = F_f \Delta d$. We do not know how much thermal energy is stored in the block or the surface, which is why we include the surface in our system.

7. **Assume.** The angle of the incline is fairly small, so we will assume the size of the friction force remains constant between events 1 and 2. Your teacher will roll the cart along the flat section of the track. Use the data from the corresponding velocity graph to determine the force of friction the cart experiences. Be sure to show the Newton's second law calculation.

8. **Predict.** Use your work-energy equations to predict the impact speed of the cart when it hits the bumper.

D: Mathematical Representation

Describe steps, complete equations, algebraically isolate, substitutions with units, final statement with a 10% uncertainty.

9. **Evaluate.** Is your answer reasonable? Explain why you think so **before** you test it!

10. **Test.** Ask your teacher to watch you test your prediction. Does it agree with your prediction? Explain.

11. **Reason.** If we didn't assume that the force of friction was constant between events 1 and 2, how would your solution process and result be different? (Don't make any new calculations.)

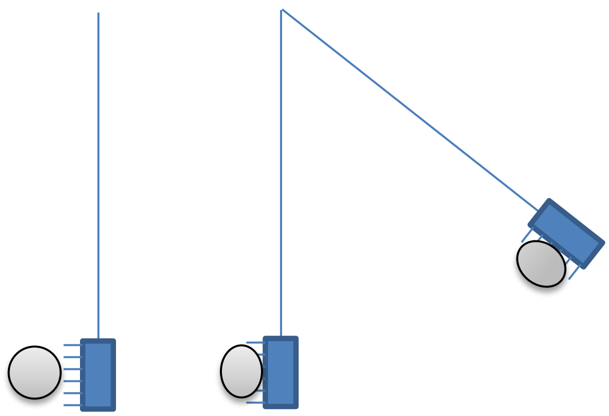
SPH4U: The Ballistic Pendulum

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

Here's a problem for you: how can you determine the speed of a bullet using only measurements of mass and distance? The answer was found in 1742 by the English mathematician Benjamin Robbins using his invention, the ballistic pendulum. Now it's your turn to repeat his clever work – but since guns are frowned upon in schools, you will launch a blob of play-doh at our ballistic pendulum.

A: Pictorial Representation

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

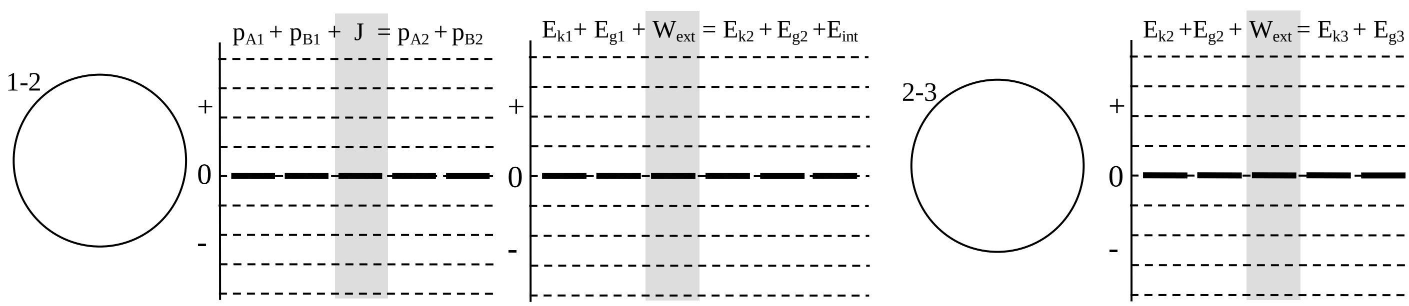


Measurements: Do these later.

Hint: There are **three** important events in this problem (not including the throw). You may assume that its velocity does not change much while traveling through the air.

B: Physics Representation

Energy / momentum bar chart, flow diagram, events



C: Word Representation

Describe motion, energy / momentum transfers, assumptions

Events 1-2:

Events 2-3:

D: Mathematical Representation

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

Now try out the pendulum and make your measurements. Record these values in your sketch for part A.

Hint: Make sure you consider the geometry of the swing carefully!

E: Evaluation

Answer has reasonable size, direction and units?

SPH4U: Spring Force and Energy

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

How does the force exerted by a spring change as we stretch it? How much energy is stored in the spring? In this investigation we will find out.

A: Force and Springs

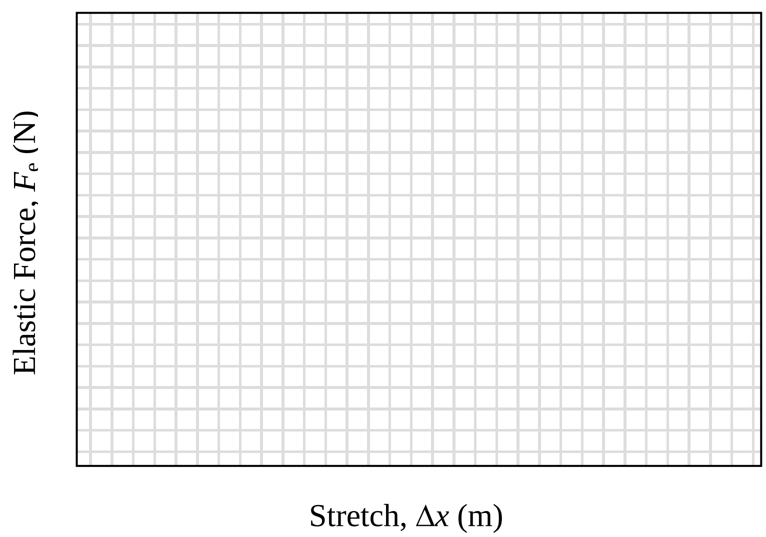
A few things about springs: Don't overstretch springs – they can be permanently deformed and damaged. The position of the end of a spring experiencing no other forces, whether oriented horizontally or vertically, is called the *equilibrium position.* Physics springs have no mass.

1. **Explain.** There is an important difference between the length of a spring and the amount of stretch. Explain this difference. Which one are you being asked to use?

2. **Explain.** Describe an experiment to **determine how the size of the spring force is depends on the amount of stretch** in a spring. Which quantity is the dependent one? A good experiment will feature many data points to reduce uncertainties and use consistent intervals to help find patterns.

3. **Represent.** Draw a sketch of your experiment showing the measurements involved.

4. **Observe.** Conduct your experiment and make your measurements.



5. **Represent.** Plot a graph that shows the relationship between your variables.

6. **Analyze.** Does the data suggest a linear or curved pattern? Use appropriate techniques to analyze the relationship in the graph. (Always show units!)

7. **Represent**. Construct an equation using the symbols F_e (the elastic force the spring exerts), Δx (the stretch of the spring), and k the spring constant (your slope) based on your graphical analysis.

8. **Predict and Test.** A mystery object is at the front of the class. You may only use your spring and meter stick to determine the mass of the mystery object with an uncertainty. Check your result with your teacher.

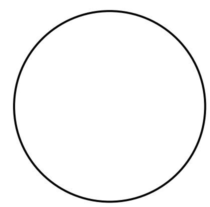
9. **Interpret.** What does the value of the spring constant, *k*, tell us about the spring itself? What would a large value indicate? What would a small value indicate? Write your *k* value on a whiteboard.

(*as a class*) The relationship found above was first discovered by Robert Hooke around 1660. Within a certain range of stretch or compression most springs behave according to **Hooke's Law**. Note that the direction of the force the spring exerts is opposite to the direction of the stretch it experiences.

Vector version: Magnitude only:

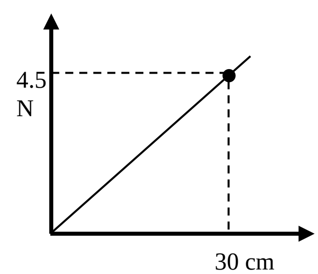
B: Energy and Springs

1. **Reason.** Why do we believe there is a flow of energy when you stretched the spring during your experiment in part A? Represent this flow with an energy flow diagram.

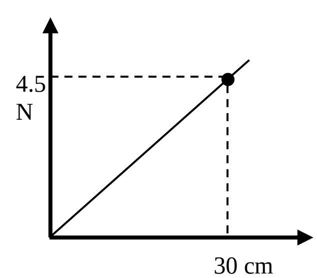


2. **Reason.** Isaac has a problem. He wants to calculate the amount of work he did while stretching his spring from 0 to 30 cm. "The force was 4.5 N when it was stretched to 30 cm. I can find the work I did by: $W = F\Delta x$ = (4.5 N)(0.30m) = 1.35 J" . Emmy says, "I'm not sure, I think your answer will be too high." Who do you agree with? Why?

3. **Reason.** The work calculation Isaac suggested can be represented as an area on a force-displacement graph. What area would this be? Shade Isaac's area on the graph to the right.



4. **Reason.** To correctly calculate the work done (Isaac was wrong!), what area on the force-displacement graph would best represent the work done? Shade your area and calculate the work value.



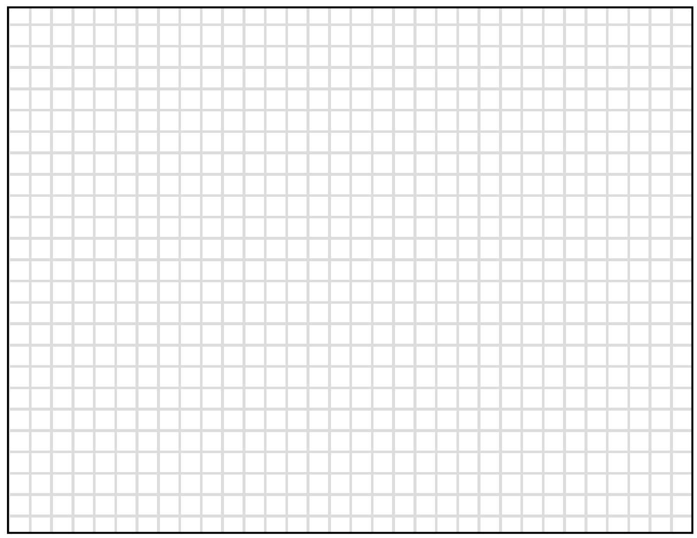
*** check your answer with your teacher ***

Work can be found by calculating the area under a force-displacement graph. This is especially helpful for forces that change magnitude.

5. **Calculate.** Complete the chart below. Calculate the work done during each increment of stretch based on your force data from earlier. Show a sample calculation below.

Displacement (stretch) from equilibrium (m)	Force (N)	Total work done by your hand (J)

6. **Represent.** Complete a graph of the total work vs. displacement. What type of pattern does the data suggest? Linear or a curve?



7. **Speculate.** Let's find the work done for any spring that has been stretched by an amount Δx and has a spring constant k. Write an equation that relates W, Δx and k. Hint: Consider how you computed the area to get the work.

*** check your result with your teacher ***

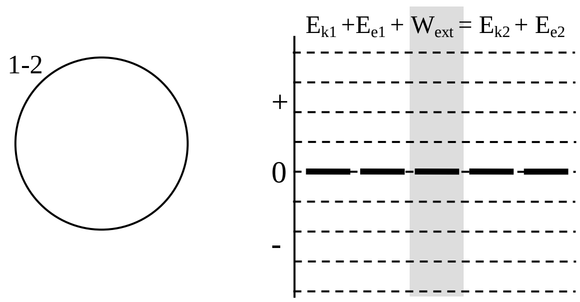
Elastic energy stored in a spring:

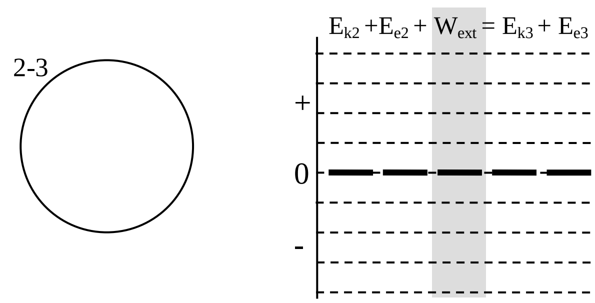
E_e =

C: The Test Launch

Your teacher has a dynamics cart set up on a track at the front of the class. It has a spring launching mechanism and pushes off a barrier at the end of a track. Your challenge is to make a few measurements and predict the launch speed of the cart. When thinking about this process, there are three important events: (1) the cart is at rest and the spring is uncompressed, (2) the spring is now fully compressed, and (3) the cart leaves contact with the barrier.

1. **Represent.** Draw an energy flow diagram for the system of the spring and cart between events 1 and 2 and between events 2 and 3. Draw an energy bar chart for each moment in time.





2. **Represent.** Construct the work-energy equations you will use to solve this problem. Simplify them.

3. **Measure.** Make any appropriate measurements to determine the quantities you will need to find the launch speed. (Hint: to find *k*, simply place a weight vertically on top of the cart's spring.)

4. Calculate and Predict. Use your measurements to predict the launch speed of the dynamics cart.

D: Mathematical Representation

Describe steps, complete equations, algebraically isolate, substitutions with units, final statement with uncertainty

5. **Test.** Use the motion detector. You probably noticed that the speed was a bit slower than you predicted. Explain why.

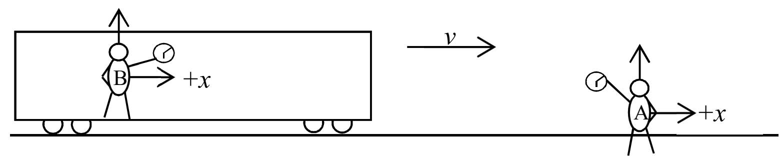
SPH4U: Velocity and Frames of Reference

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

In this new unit, we will talk a lot about observers and frames of reference. We imagine each observer carrying around a set of metre sticks which serve as a coordinate system for measuring distances, and a stopwatch for measuring time. Together, these devices define the observer's *frame of reference*.

A: The Train Ride

Alice is standing on the earth and watches a train go by with a velocity of 150 km/h [E]. Inside the train stands Bob. Both Alice and Bob are physicists and make observations about each other's motion.

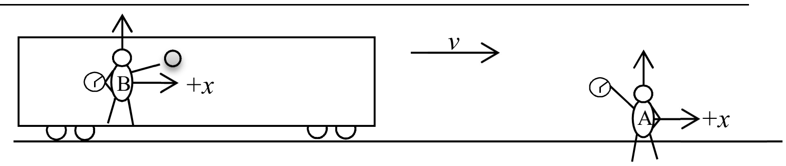


1. **Reason.** Complete the chart showing the velocity of each object as measured from each reference frame.

Object	Frame A (Alice)	Frame B (Bob)
Alice		
Bob		
Earth		
Train		

B: The Ball Toss

Bob has a ball and throws it. He measures the velocity of the ball to be 40 km/h [E]. The train keeps going at its usual speed.



1. **Reason.** Complete the chart showing the measured velocity of the ball as measured in each reference frame. **Explain** how you found the velocity of the ball relative to frame A.

Object	Frame A (Alice)	Frame B (Bob)
Ball		

2. **Reason.** Bob throws a second ball and measures the velocity to be 30 km/h [W]. Complete the chart showing the measured velocity of the ball from each reference frame. **Explain** how you found the velocity of the ball relative to frame A.

Object	Frame A (Alice)	Frame B (Bob)
Ball		

C: Turn on the Light

1. **Calculate.** Bob pulls out a flashlight, points it east and turns it on. Using a fancy apparatus he measures the velocity of a particle of light (a photon) from his flashlight to be 300 000 000 m/s [E]. Using the previous logic, what is the velocity of the light relative to Frame A in m/s?

2. **Calculate.** Imagine Bob was on an "express" train that travelled at 2×10^8 m/s [E] and turned on his flashlight just as in the previous question. What is the velocity of the light relative to Frame A?

3. **Reason.** Alice also has a flashlight (all the cool kids have them). She turns hers on as Bob's train is passing by. It releases a photon of light that travels in the same direction as Bob's express train. How does the speed of her photon compare with Bob's?

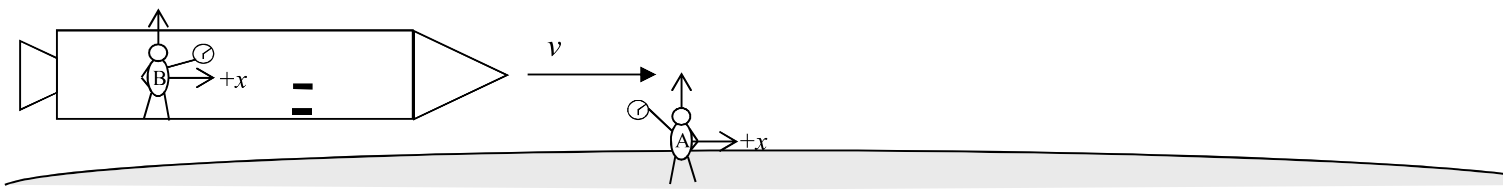
SPH4U: Do You Have the Time ?

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

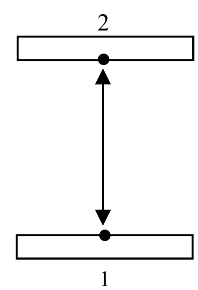
Einstein thought deeply about the train scenario we studied last class. As a result, he proposed two ideas that are called the postulates *of special relativity*:
(1) All observers in an inertial reference frame will observe light to travel at c = 2.998 x 10^8 m/s in vacuum.
(2) The laws of physics are the same for all inertial reference frames – there are no special rules if you are moving fast or slow.

Reminder: In this unit, we will talk a lot about observers and frames of reference. We imagine each observer carrying around a set of metre sticks which serve as a coordinate system for measuring distances, and a stopwatch for measuring time. Together, these devices define the observer's *frame of reference*.

A: The Rocket and Mirrors



Bob is in a spacecraft and is travelling past Earth at a very fast velocity, *v,* in the positive *x*-direction. Onboard, he has carefully set up a pair of mirrors that face each other, separated by a small distance. A particle of light (a photon) travels back and forth between the mirrors, reflecting from the same two points on the mirror's surface. Alice is standing on the Earth watching Bob and his mirrors travel by. Both Bob and Alice have identical stopwatches that they use to measure the time interval between two events: (1) the photon leaves the bottom mirror, and (2) the photon reaches the top mirror.

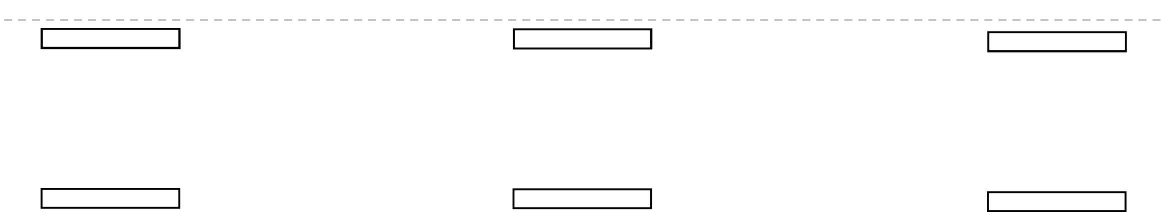


1. **Reason.** Complete the chart of measurements from **Bob's** frame of reference and label the diagram.

Time interval between events1 and 2	Δt_o
Distance between events1 and 2	Δd
Speed of the photon	

2. **Represent.** Construct an equation that relates the speed of the photon to the distance and time it travels as measured in **Bob's** frame.

3. **Represent.** From **Alice's** frame of reference, she sees the mirrors at three moments in time: event (1), event (2), and event (3) the photon returning to the bottom mirror. Note that the rocket is travelling quite fast! Draw the path of the photon through space. Label the distance between events 1 and 2 as ΔD.



4. **Reason.** Complete the chart of measurements from **Alice's** frame of reference.

Time interval between events 1 and 2	Δt
Distance between events 1 and 2	ΔD
Speed of the photon	

5. **Represent.** Construct an equation that relates the speed of the photon to the distance and time it travels as measured in **Alice's** frame.

6. **Reason.** Compare the size of the results from the two frames of reference.

Measurement	Comparison
Speed of photon	
Distance between 1 and 2 (Δd vs. ΔD)	
Time interval between 1 and 2 (Δt vs. Δt_o)	

Note that both observers **must** agree on the speed of light according to the first postulate of special relativity.

7. **Speculate.** It turns out that the results of this comparison apply not just to the time interval between the two events of the photon and mirrors, they apply to any pair of events that occur at the same x-position according to Bob: for example, Bob talking, playing the guitar, breathing, growing fingernails and so on. What does your comparison imply about the amount of time these processes take as measured by Alice?

B: Time Dilation

A direct consequence of Einstein's postulates is that two observers moving relative to one another (like Bob and Alice) will disagree on the amount of time that passes between each pair of events. One observer will measure less time between the events, which means he observes time flowing faster. The other will measure more time between the events, which means she observes time is flowing slower. This is not an optical illusion, a delay effect, or a defect of any clock. The flow of time an observer measures depends on the observer's speed relative to the events. This idea is called *time dilation*. We introduce two definitions:

Proper time (Δt_o): The time interval measured between two events that occur at the same position in space.
Relativistic time (Δt): The time interval between two events that occur at two different positions in space.

The relativistic time interval will always be greater than the proper time interval ($\Delta t > \Delta t_o$). In this unit, you must always decide whether the time interval you are studying is proper or relativistic. Similarly, there is no single correct answer to the question, "how much time does it take?", because the amount of time depends on who is making the measurement.

1. **Explain.** Alice has a toaster. She puts in a piece of bread and starts the toaster. Bob travels by in his rocket and measures the time interval for toasting the toast. Alice also measures this time interval. What are the two events Alice and Bob use to start and stop their clocks? Use these events to explain what type of time interval each is measuring.

***call your teacher over to discuss your ideas* **

2. **Explain.** Bob is still traveling on the rocket and is getting hungry. He cooks his dinner on the rocket's stove, which takes 17 minutes according to his measurements. According to Alice, it takes Bob 31 minutes to make his dinner. Explain in two different ways what type of time interval each of them measures.

Two observers moving relative to one another will measure different amounts of time between the same pair of events. This **does not lead to any kind of logical contradiction**. A contradiction in physics only occurs when two observers in the **same** frame of reference measure different results (outside of their range of uncertainties). Thanks to Einstein, we now understand that measurements by moving observes will not agree, but there is a careful relationship between their relative speed and different measurements, as we will see shortly.

C: Name that Interval

A critical step in solving relativity problems is to carefully determine the type of time intervals you are working with. We show this in Part A and explain it in Part C of the solution process. Here are the guidelines for your homework.

A: Pictorial Representations
- Draw and label a reference frame (*x-y axis*) to help illustrate the important events and the given information
- List the given information according to the frame in which that value was measured. Carefully label the intervals as proper or relativistic.
- Clearly illustrate and describe the events used to define the problem

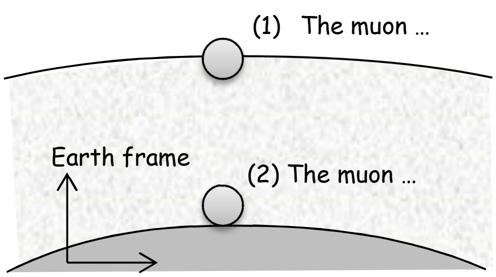
C: Word Representations
- Describe the motion and explain what types of intervals are involved.

1. **Represent.** Practice relativity problems can be found at the end of this unit. Parts A and C have been started for question #1. Complete anything that is missing in Parts A and C for the example below. Note that we are not focusing on distances today. **Don't do any math!**

A: Pictorial Representation

Sketch showing events, title your sketch to identify the frame of reference, coordinate system, describe events, label givens & unknowns with symbols (in place on the sketch), conversions, table of measurements and unknowns in each FOR.

Earth FOR	Muon FOR
Δt =	Δt_o = ?
Δy_o = 60 km	



C: Word Representation

Describe motion, explain types of intervals (givens only)

The muon is…

The time interval measured in the Earth frame is ____________ because the two events …

D: Mathematical Representation

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

E: Evaluation

Answer has reasonable size and units? Explain why.

2. **Represent.** Use the relativity solution sheets and complete parts A and C for Relativity problems #2-4 at the end of the unit. Don't do any math! Note: we haven't learned how to label the distance intervals yet, so just label them Δx in your work for now, you will improve them later!

SPH4U: Space - The Final Frontier

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
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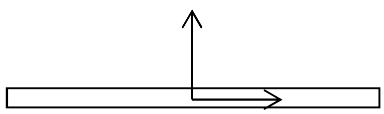
A subatomic particle called the muon is moving rapidly at a speed v past a ruler. There are two events: (1) the muon is at the 0 centimeter mark, and (2) the muon is at the 30 centimeter mark of the ruler. You need a ruler, an eraser (muon), and a thumb as your pretend stopwatch for this investigation.

A: The Ruler's Frame

1. **Represent.** Sketch this situation and label the two events in the frame of reference of the ruler. Indicate the velocity, v, of the muon and the distance the muon travels between the two events Δx_o.

A: Pictorial Representation

Sketch showing events, title your sketch to identify the frame of reference, coordinate system, describe events, label givens & unknowns with symbols (in place on the sketch), conversions, table of measurements and unknowns in each FOR.



ruler frame

2. **Explain.** Act out this situation using the frame of reference of the ruler. One person is the muon, another pretends to use a stopwatch. The third points to each event, saying out loud "1!" and "2!". Explain what type of time interval you measured. What symbol should you use to represent it? **Demonstrate this for your teacher (practice first!)**.

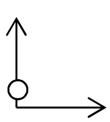
3. **Represent.** Write an equation that relates speed, distance and time of the muon as measured by an observer in the ruler's frame.

B: The Muon's Frame

1. **Represent.** Sketch this situation in the muon's frame of reference and label the two events. Make sure your diagram clearly shows the two events. Indicate the velocity of the ruler v and the distance the ruler travels between events 1 and 2, Δx.

A: Pictorial Representation

Sketch showing events, title your sketch to identify the frame of reference, coordinate system, describe events, label givens & unknowns with symbols (in place on the sketch), conversions, table of measurements and unknowns in each FOR.



muon frame

2. **Explain.** An observer in the muon's frame of reference measures the time interval between events 1 and 2. Act out this situation from the frame of reference of the muon. **Demonstrate this for your teacher**. Explain what type of time interval you measured. What symbol should you use to represent it?

3. **Represent.** Write an equation that relates speed, distance and time for the ruler as measured by an observer in the muon's frame.

4. **Reason.** Compare the size of the results from each frame.

Speed of muon / ruler	
Time between events 1 and 2	
Distance muon / ruler travels	

5. **Reason.** What can we conclude about the distance measurement of each observer?

C: Length Contraction

The second consequence of Einstein's two postulates is that the distance between two events also depends on the frame of reference! Moving objects (or intervals of space) become smaller along their direction of motion. This is called *length contraction*. A ruler moving towards us contracts. If we travel past Earth and the moon, the space between Earth and the moon will contract. We define two different types of distances or lengths:

Proper length (Δx_o): The distance between two particles (or particles on one or two objects in space) that are at rest relative to an observer.
Relativistic length (Δx): The distance between two particles (or particles on one or two objects in space) that are moving relative to an observer.

The relativistic length is always smaller than the proper length ($\Delta x < \Delta x_o$).

1. **Reason.** Bob is on the rocket travelling past Earth. Both Alice and Bob measure the length of the rocket. How does Bob's measurement compare with Alice's? Explain.

2. **Represent.** Last class, we started a problem involving a muon travelling through Earth's atmosphere. Complete the word representation of that problem by explaining what type of distance the 60 km is.

3. **Represent.** Complete the distance parts of the relativity problems in last class's homework (problems #3-4). Use relativity solution sheets to complete parts A and C for problems #5-7

SPH4U: The Gamma Factor

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
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A: Why Don't We Notice?

The consequences of Einstein's two postulates seem really crazy to us, largely because we have never noticed these changes to time and length intervals. Why have we never noticed time slowing down or lengths contracting for cars on the highway?

To figure out how much larger the relativistic time interval is, we can do a mathematical analysis of the photon travelling between Bob's mirrors and carefully compare ΔD with Δd. If we do this (try it – it's fun!) we get the gamma factor:

$$\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$$

where γ is the greek letter "gamma". Gamma is the ratio between the measurements observers will make in different frames that are moving relative to one another. As a result, we can use gamma to convert or *transform* the time interval measured by an observer in one frame into that of an observer in the other frame. The two transformation relationships are:

$$\Delta t = \gamma \Delta t_O \qquad \Delta x = \frac{\Delta x_O}{\gamma}$$

1. **Calculate.** Let's go back to Bob in his rocket and Alice on Earth (B#2 pg. 113). Both Bob and Alice measured the time for Bob to cook his dinner. What is the value for gamma that relates their time measurements?

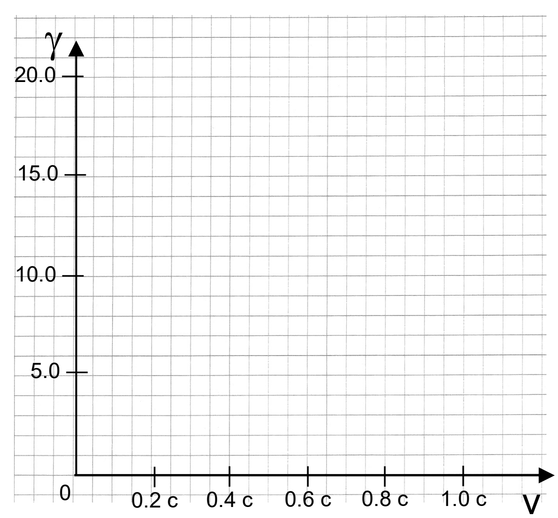
2. **Calculate.** Now that you know gamma for this situation, you can use it to find other things. While Bob was cooking his dinner, Alice measured the length of the rocket and found a value of 127 m. According to Bob, how long is the rocket?

When objects move fast compared with the speed of light, it is helpful to convert velocities into units of *c*. For example, $v = 1.5 \times 10^8$ m/s = 1.5×10^8 m/s $\left(\frac{1\,c}{2.998 \times 10^8\ m/s}\right)$ = 0.5 *c*. When you substitute the velocity this way into γ, the *c*'s divide out nicely and the math is **much** friendlier.

In relativity we often encounter extreme numbers. We need to count significant digits by the digits which **are not 9** for velocities in terms of *c* (0.999458 *c* has three significant digits).

3. **Calculate and Represent.** Now we want to practice using speed to find gamma. Convert the first five speeds to units of *c*. Calculate γ for each speed. When possible, record γ with three or four significant digits. Sketch a graph of γ vs. *v*.

Speed (m/s)	Speed (c)	γ
Fast Runners, 10 m/s		
Fast Cars, 40 m/s		
Fast Jets, 600 m/s		
Earth satellites, 7 860 m/s		
Voyager Space Probe, 17 000 m/s		
TV screen electrons	0.2 c	
	0.4 c	
	0.6 c	
	0.8 c	
	0.99 c	
X-Ray Machine Electrons	0.999 c	
LHC protons, 0.999 999 999 95 c		



4. **Explain.** Are the first five γ values you calculated *exactly* equal to one?

5. **Explain.** Based on the chart, offer a simple explanation for why relativistic effects are not noticed in daily life.

6. **Describe.** What happens to the size of γ as v approaches the value c?

7. **Reason.** What does this tell us about the flow of time for a highly relativistic object (speeds close to c)?

6. **Apply.** Relativistic effects are important for GPS satellites, which move very fast relative to the ground. Precision timing is absolutely essential for determining an object's location on the earth. For a GPS satellite observed from the earth, γ = 1.000 000 000 3.
   a) One day (86400 s) ticks by on a clock in the GPS satellite. How much time does this take according to an observer on Earth? What is the difference in the two times?

   b) How far does light travel during that time difference? The GPS system uses microwave signals that travel at the speed of light to locate you. What does this mean for the reliability of the GPS system?

B: Relativity Problem Solving

Now that we have mathematical tools at our disposal, we are ready to solve the problems we have started over the past few lessons. Here are some important tips for the math part of our relativity work.

D: Mathematical Representation

- When possible, find a numerical value for γ first: this is a valuable check for your work. In multi-part problems, you might use γ more than once, so this simplifies your work.
- A convenient unit of distance is the light year: 1 ly = c· a (speed of light × year). If your calculations involve light-years (ly) of distance and years of time (a = year), you do not need to convert anything, just replace the unit ly with c·a to show how the units multiply or divide out. e.g. $\Delta t = \Delta x_o / v$ = 20 ly / 0.5c = 20 c·a/0.5c = 40 a
- Remember to keep at least 4 significant digits during your math work and use 3 for the final answers.

E: Evaluate

- Based on your understanding of relativistic or proper intervals, you should be able to decide if the results should be larger or smaller than the givens.

1. **Solve.** Complete the solution for the muon in the atmosphere question you started in an earlier lesson.

2. **Solve.** Complete the solutions for the relativity questions #1, 2, 5, and 6.

SPH4U: Relativity and Energy

Recorder: ___________________
Manager: ___________________
Speaker: ___________________
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The consequences of Einstein's bold suggestion, that the speed of light is constant for all inertial reference frames, go far beyond just space and time – they also extend to our notions of energy. Using a clever argument, Einstein created the world's most famous equation:

$$E = \gamma mc^2, \text{ where } \gamma = (1 - v^2/c^2)^{-1/2}$$

This is usually written, for the general public, as $E_o = mc^2$, where the "$_o$" is carelessly left out! Sometimes physics ideas stretch beyond our common sense and we begin to rely on equations to help us understand how our universe works. Let's explore this equation and try to figure out what it tells us about energy.

A: The Mass-Energy Relationship

1. **Reason.** Describe carefully how this energy depends on the speed of an object.

2. **Reason.** What type of energy depends on an object's speed? What type of energy does Einstein's equation keep track of?

3. **Reason.** According to the equation, how much energy does an object have when it is at rest? Explain how the equation for E becomes the equation for E_o. Is Einstein's equation still describing kinetic energy?

4. **Reason.** When at rest, what is the only characteristic of the object that could be changed and affect the amount of energy E_o? What does this suggest about where this energy might be stored?

An object at rest possesses a form of energy called its *rest energy*, E_o, Einstein's complete expression ($E = \gamma mc^2$) gives the **total energy** of the object, which always includes the rest energy and possibly some kinetic energy depending on the object's speed. According to our best experiments, this new equation is correct under all circumstances and replaces what we have previously learned.

5. **Represent.** Write an expression that shows the relationship between E, E_o and E_k.

*** check this with your teacher before moving on ***

B: Relativistic Energy

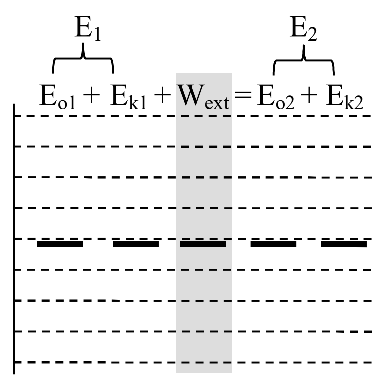
1. **Explain.** How can you use Einstein's equation to find the kinetic energy?

2. **Calculate.** Consider a 1.0 kg "microspacecraft" that is initially at rest. It experiences a force from a laser beam that causes it speed up over a long period of time. We want to try calculating its kinetic energy in two different ways: (1) using $\frac{1}{2}mv^2$ in the "Before Einstein" column in the chart below, and (2) using Einstein's equation in the "After Einstein" column. **Show your work and give results in units of joules.**

Speed	Before Einstein (B. E.)	After Einstein (A. E.)
0.1 c		
0.6 c		

3. **Reason.** Under what condition is the expression $\frac{1}{2}mv^2$ valid? What should we conclude about the limitations of the traditional kinetic energy equation?

4. **Represent**. A powerful gun launched the 1.0 kg block described above. Complete an energy bar chart for the system of the block before and after its launch.



Accelerating an object to speeds near that of light is extremely challenging. With our current technology, we can only accomplish this for really small things like atoms and sub-atomic particles. According to Newton, all we need to do is exert a steady force on something for long enough and the uniform acceleration will eventually cause the object to reach 3.0×10^8 m/s and our science fiction dreams will come true! According to Einstein, things are different.

5. **Reason.** How much energy is required to bring the 1.0 kg block to the speed of light? Explain the mathematical difficulty with performing this calculation. What does this result tell us about the physical difficulty of reaching the speed of light?

This is the main reason why the latest and greatest particle accelerator, the Large Hadron Collider ($ 9 000 000 000), is such a colossal engineering feat. A tremendous amount of energy is required to accelerate the collider's protons to 0.999 999 991 c.

C: Particle Physics

1. **Calculate.** A proton is a very small particle with a mass of 1.673×10^{-27} kg. How much energy is stored in the mass of the particle?

> Subatomic particles usually possess very small quantities of energy. A new unit is needed to conveniently notate these small energy values. One *mega-electron volt* (MeV) is a unit of energy equivalent: 1 MeV = 1.602×10^{-13} J.

2. **Calculate.** Find the proton's rest mass energy in units of MeV.

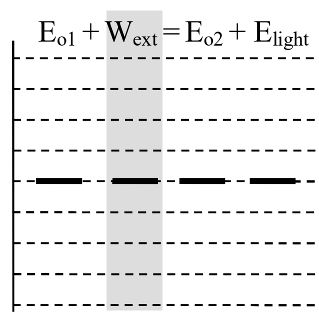
3. **Explain.** Physicists often write the mass of the proton as 938.3 MeV/c^2 out of convenience. Calculate the rest-energy of the proton using this mass. Explain why it is so convenient to use these units for mass.

4. In a typical fusion reaction (like in the sun), a deuterium particle (1876 MeV/c^2) fuse with a tritium particle (2809 MeV/c^2) producing a helium nuclei (3729 MeV/c^2) and a neutron (937 MeV/c^2):

$$D + T \rightarrow He + n$$

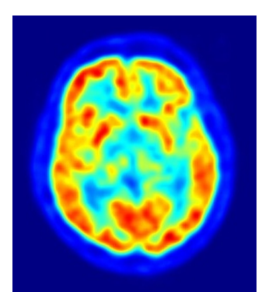
   (a) **Reason.** How does the mass of the reactants compare with the mass of the products? What happened to the mass? What does this imply about the conservation of mass? Speculate on a new, better conservation law.

   (b) **Represent.** An improved version of the reaction equation would include energy: D + T → He + n + light energy. Draw a energy bar chart showing how energy is stored before and after the fusion process. Note that E_{o1} represents the rest energy of all the particles before the reaction.



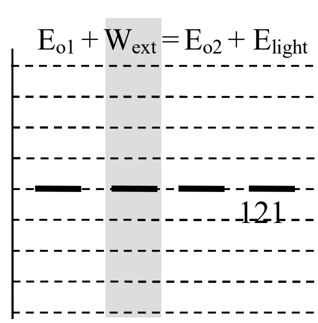
   (c) **Calculate.** How much energy is released during the fusion process? Give your answer in joules and electron volts.

5. The conversion of matter to energy can be total if a matter particle collides with a corresponding anti-matter particle. This is the *raison d'etre* of the Large Hadron Collider: to collide protons and anti-protons, which releases a tremendous amount of energy. This is also the physics behind the medical imaging technique positron imaging tomography (PET scans), where an electron collides with a positron (the anti-electron). In the case of the PET scan, radioactive materials are injected into the blood stream of a patient. The decay process releases a positron (an anti-electron) which collides with an electron of a nearby atom. In the process, the two particles annihilate and produce two gamma-ray photons (γ).



$$e^- + e^+ \rightarrow \text{light energy}$$

   (a) **Represent.** Complete an energy bar chart for the PET process described above. Note that we are using one bar for the total rest energy before the process.

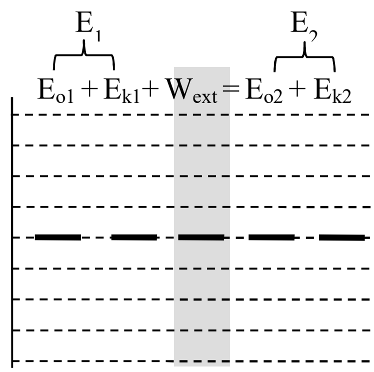


(b) **Calculate.** How much energy is released when an electron (0.511 MeV/c^2) collides with a positron (same mass) and the two annihilate (leave no mass behind)? You may assume they are both essentially at rest.

6. An electron (0.511 MeV/c^2) in an old-fashioned television (cathode ray tube) is accelerated by an electric field to a very great speed. The electron gains 0.01675 MeV as it speeds up.

(a) **Calculate.** What is the speed of the electron (in units of c) using the old-fashioned $\frac{1}{2}mv^2$ equation?

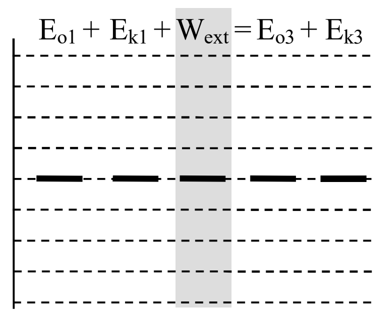
(b) Represent and Calculate. Complete an energy bar chart for the system of the electron. Calculate the speed of the electron using the Einstein's equation for energy. Hint: Find a result for γ first, then find v. Use the result for γ to help explain why your result from question #6a was reasonably accurate.



7. **Calculate.** We have seen examples of mass being converted into energy. Amazingly, the opposite is also possible! Energy can be converted into the mass of a particle – antiparticle pair:

$$e^- + e^+ \rightarrow \text{light energy} \rightarrow p + \bar{p}$$

In this case, all the energy of the electron-positron pair is converted into the mass of the proton and anti-proton. After this process the proton and anti-proton are moving **very** slowly. This is exactly what used to happen at the LEP (Large Electron Positron) collider at CERN in Switzerland. What should the speed be of an electron and positron in the LEP to allow this to happen? (m_e = 0.511 MeV/c^2, m_p = 938.3 MeV/c^2)



SPH4U: Relativity Problems

1. A cosmic ray (a muon) enters Earth's atmosphere 60 km above Earth's surface. It reaches a detector on the ground after travelling 400 μs ($\mu = 10^{-6}$) in the atmosphere, as measured by experimenters on the ground. How long does the journey take according to the muon?

2. You and your friends here on Earth are watching a live video showing a clock onboard a fast moving rocket (more popular than fireplace videos). At one moment the clock in the video reads 10:23 am and at another moment it reads 10:29 am. You noticed that 12 minutes elapsed on your own clock. What speed was the rocket moving at?

3. An astronaut travels to a star system 4.5 ly away as measured by Mission Control at a speed of 0.9 *c*. Assume the times needed to speed up and slow down are negligible. (a) How much time does the journey take according to Mission Control on Earth? (b) How long does the journey take according to the astronaut?

4. An astronaut travels on a journey to a distant star, leaving Earth at the age of 46 years and arriving at the star when she is 61 years old. Scientists at mission control on Earth measured that the trip takes 120 years. What was the speed of the rocket? According to the scientists, how far away is the star?

5. Jill claims that her new rocket is 100 m long. As she flies past your house, you measure the rocket's length and find that it is only 80 m. What is Jill's speed?

6. A muon travels 60 km through the atmosphere (similar to question #1) at a speed of 0.9997 *c*. According to the muon, how thick is the atmosphere?

7. Our Milky Way galaxy is 100,000 ly in diameter. A spaceship crossing the galaxy measures the galaxy's diameter to be a mere 100 ly. (a) What is the speed of the spaceship relative to the galaxy? (b) How long is the crossing time as measured in the galaxy's frame of reference?

8. A muon (1.883×10^{-28} kg) enters the atmosphere with a speed of 0.8 *c*. When it reaches the ground, it is traveling at 0.7 *c*. How much energy (in joules) did it lose?

9. During radioactive beta-decay, a neutron (1.6749×10^{-27} kg) at rest decays into a **very** slow moving proton (1.6726×10^{-27} kg) and a fast electron (9.109×10^{-31} kg). What is the speed of the electron? (Hint: find the total energy of the electron)

10. In an attempt to reduce the extraordinarily long travel times for voyaging to distant stars, some people have suggested travelling close to the speed of light. Suppose you wish to visit the red giant start Betelgeuse, which is 430 ly away, and that you want your 20 000 kg rocket to move so fast (0.99892 c) that you age only 20 years during the journey.
    (a) What is the distance between Earth and Betelgeuse according to an observer in the rocket?
    (b) How much energy is needed to accelerate the rocket to this speed?
    (c) Compare this amount of energy to the total used by the United States in the year 2010, which was roughly 1.0×10^{20} J.

11. The nuclear reaction that powers the sun involves the fusion of four protons ($m_p = 1.673 \times 10^{-27}$ kg) into a helium nucleus ($m_{He} = 6.645 \times 10^{-27}$ kg). The process involves several steps, but the net reaction is simply: 4p → He + energy. How much energy is released overall in each fusion process? Give your answer in J and MeV.

12. Consider the inelastic collision: $e^- + e^+ \rightarrow e^- + e^+ + e^- + e^+$ in which an electron-positron pair is produced in a head-on collision between an electron and positron moving in opposite directions at the same speed. All the particles are moving **very** slowly after the collision.
    (a) What is the total kinetic energy of the electron and positron before the collision?
    (b) What is the speed of an electron with this energy?

1. 347 μs
2. 0.866 *c*
3. (a) 5 yr, (b) 2.18 yr
4. 0.992 *c,* 119 ly
5. 0.6 *c*
6. 1.47 km
7. (a) 0.9999995*c*, (b) 100 000.05 yr
8. 4.52×10^{-12} J
9. 0.918 *c*
10. (a) 19.98 ly (b) 3.69×10^{22} J, (c) 369 times greater!
11. 4.22×10^{-12} J, 26.4 MeV
12. (a) 1.022 MeV, (b) 0.866 *c*

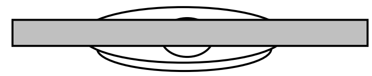
From R. Knight, *Physics for Scientists and Engineers. A Strategic Approach.* Pearson Education, 2013

SPH4U: The Static Electric Interaction

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

A: Observe and Find a Pattern

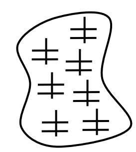
You will need: 2 ebonite rods, 2 sheets of acetate and a watch glass. Carefully balance one ebonite rod (rod A) on the watch glass. Keep it in place with a small ball of tape – see the diagram to the right. Now you are ready to investigate how the ebonite rod interacts with other materials.



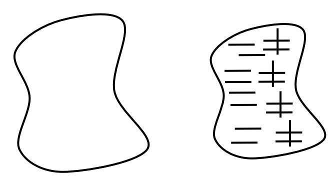
1. **Observe.** Vigorously rub the objects as described below. Bring them close and look for an interaction. Sometimes the watch glass gets stuck and needs a little tap. Record your observations. (Hint: all three are different!)

A:	Rod A unrubbed	Rod B unrubbed	
B:	Rod A rubbed with acetate	Rod B rubbed with acetate	
C:	Rod A rubbed with acetate	The acetate that rubbed rod A	

2. **Interpret.** According to your observations, how do similarly charged objects interact? How do differently charged objects interact? How to uncharged objects interact?

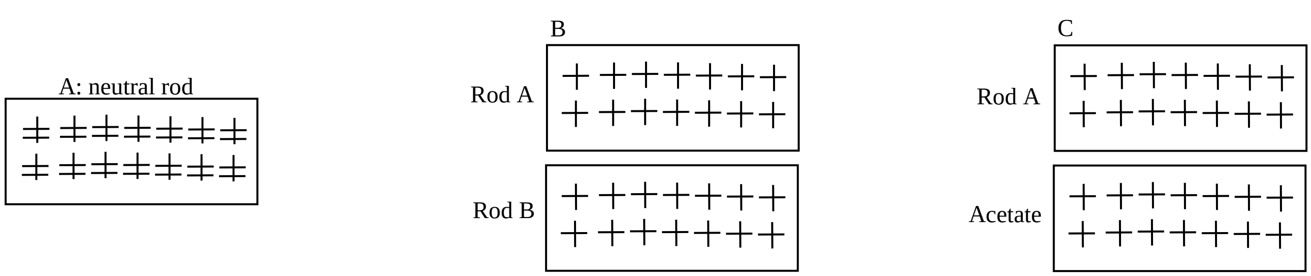
We model ordinary, uncharged matter as a substance consisting of very large, but equal, quantities of positively and negatively charged particles. Careful physics experiments indicate that only the negatively charged particles are able to move in solid materials. Therefore, when an object is rubbed, negatively charged particles (the valence electrons) can either be added to or removed from the material. When a valence electron leaves, the remaining atom (the ionic core) is positively charged. We can represent these two parts (the electron and the ionic core) with *charge-pairs* represented by a positive and negative charge. A *charge diagram* shows a selection of these many charge pairs in the material and illustrates movement of the negative charges. Note that the pairs are drawn with the "+" and "-"symbols *overlapping*. This indicates a neutral atom in the material.	Ordinary Matter 

3. **Reason**. The piece of ordinary matter shown above is rubbed on the left-hand side and gains some negative charge. A student draws a new charge diagram showing the charges after rubbing, but it is wrong. Explain the errors in the student's diagram and draw a correct one.



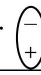
After – correct! After – wrong!

4. **Explain.** Use the charge-pair model to explain the patterns observed in the previous experiment. Complete the charge diagrams below to help illustrate situations B and C from question A#1 above. Draw a vector for the force each object experiences. The ebonite rod gains electrons when rubbed with acetate.



B: The Unrubbed Rod

1. **Observe.** Place a fresh, unrubbed rod (rod A) on the watch glass. Rub one end of another rod (rod B) with acetate. Bring the rubbed end of rod B near rod A. Describe the interaction you observe.

> The atoms and molecules in an insulator hold electrons close to the atoms (including any added electrons) and do not allow them to move freely throughout the material. When there is an electric interaction with another object, the valence electrons of the insulator shift around the atoms in response, but don't travel away from the atomic nuclei. To show that the valence electrons shift and are still bound to the ionic cores, we draw a small circle around the charge pair.  We say that the material is now polarized (still neutral, but with a small separation of charges).

2. **Explain.** Why do the rods interact as you observed? Complete a charge diagram for each rod during their interaction. Ebonite is a plastic and an insulator.

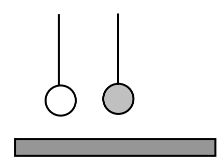
3. **Predict and Test**. You are curious to know what will happen if you rub rod B with acetate and bring the **acetate** near the unrubbed rod. (If this doesn't work, try rubbing the acetate on the table.)

Prediction	Explain your prediction + Draw charge diagram	Observations

C: The Two Spheres

Your teacher has set up two Styrofoam spheres hanging side by side from the edge of a table. One sphere is covered with aluminum foil.

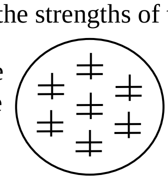
1. **Observe**. Rub a rod with acetate. **Very slowly** bring the rod closer to both spheres. Try to keep the rod parallel to the table edge. Describe the interaction between the spheres and the rod. **Note:** this works best the first time – once the spheres touch the rod a new effect takes place.



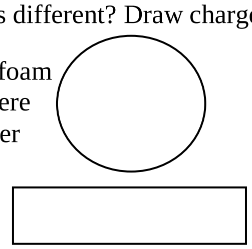
> The electrons of conductors (the foil, a metal, is a conductor) are not bound to a particular atom. The conduction electrons in a metal are free to move **any** distance throughout the material. The conduction electrons repel one another, so they don't all bunch up in one location. Due to the mobility of the conduction electrons, a metal will become polarized when it interacts with a charged object.

2. **Explain**. Why are the strengths of the interactions different? Draw charge diagrams showing these differences.

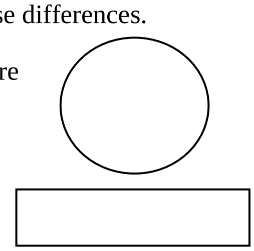
sphere before



Styrofoam sphere after



foil sphere after



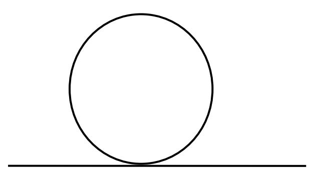
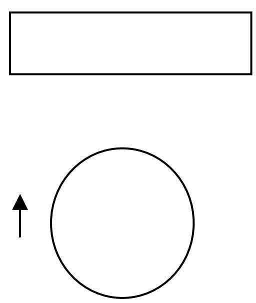
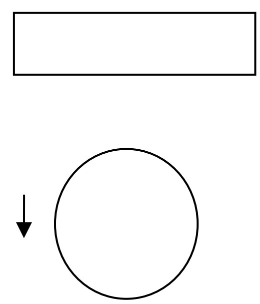
3. **Reason**. Based on your observations, which sphere was polarized the most strongly? What do we mean by saying "polarized most strongly"?

D: Party Time - Confetti

You are throwing a party for a friend and happen to have two kinds of confetti – the traditional paper kind and confetti made from aluminum foil (you though it might be nice and sparkly). Since your friend is late, you decide to try an experiment. You rub a rod with acetate and hold it close above a little pile of each type of confetti. Don't do it yet! Complete the chart below. The piles of confetti are set up at the front of the room.

	Predict what you will observe	Explain your prediction	Do the experiment and record your observations	Revise your explanations, if necessary
Paper Confetti				
Aluminum Confetti				

5. **Explain**. Explain in three steps what happens to the charges of an aluminum confetti particle during this experiment. Draw a charge diagram **and** show the electrostatic forces for the rod and confetti particle in each step.

The confetti on the table before the rod is charged.	The confetti travels upwards towards the charged rod.	The confetti has touched the rod and is travelling downwards
		

E: Apply Your Understanding!

1. **Predict**. What will happen if you place a charged rod near a falling stream of water from a tap? Explain your prediction using a charge diagram for a droplet of water and rod. You may assume that the water droplet is neutral. Draw a second illustration the path of the entire stream of water.

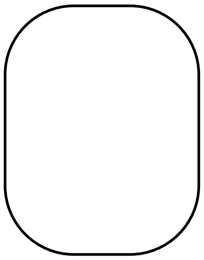
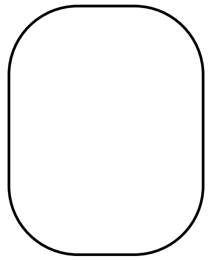
2. **Test**. Try it out and describe any changes that might be necessary to your explanation above.

SPH4U: A New Kind of Interaction Homework Name:

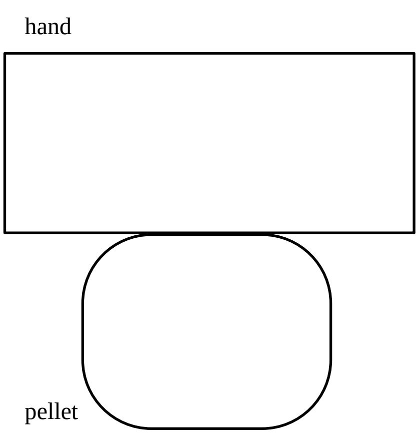
A: Annoying Sticky Packing Foam

Have you every unpacked a box that was filled with packing foam (small pieces of white Styrofoam)? If you have, you surely noticed that these little pieces of foam easily stick to your hands, the box, walls and many other surfaces.

1. **Represent and Explain.** When the foam pellets are transported in a box, they rub against the box itself or the objects inside and gain a net positive charge. Draw a charge diagram for the foam pellet before and after it was rubbed. Explain the differences between the two diagrams.

Before	After
	

2. **Represent and Explain.** In this situation, your hand behaves as an electrically neutral insulator. The charged foam pellet sticks to your hand - even when you hold your hand horizontally, it sticks underneath. Draw a charge diagram for your hand and the foam pellet while the pellet is stuck underneath your hand. Draw an interaction diagram and force diagram for the system of the foam pellet (use the symbols *e* and F_e for the electrostatic interaction and forces). Explain what happens to the charges in your hand.

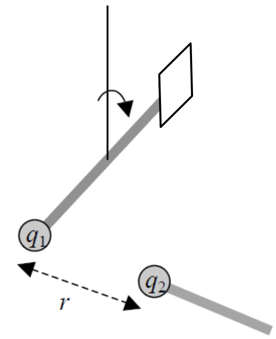
Charge Diagram	Interaction Diagram	Force Diagram
		

3. **Calculate.** You try to shake the foam pellet (0.5 g) off you hand. While doing this, your hand and the foam pellet accelerate upwards (it stays attached!) at 12.9 m/s^2. In this situation, the normal force is small enough to be ignored. What is the size of the electrostatic force?

SPH4U: The Strength of Electrostatic Interactions

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

In 1785 Charles Coulomb used a torsion balance to measure the force that one charged sphere exerts on another charged sphere to find how the force between two electrically charged objects depends on the magnitudes of the two charged objects and on their separation. Coulomb could not measure the absolute magnitude of the electric charge on the metal spheres. However, he could divide the charge in half by touching a charged metal sphere with a third identical uncharged metal sphere.



A: Looking for Patterns

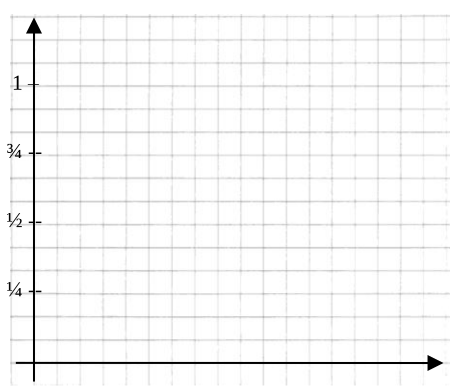
1. Explain the mechanism behind his method of dividing the charge and provide an illustration. Why did he have to use metal spheres? Would plastic spheres work?

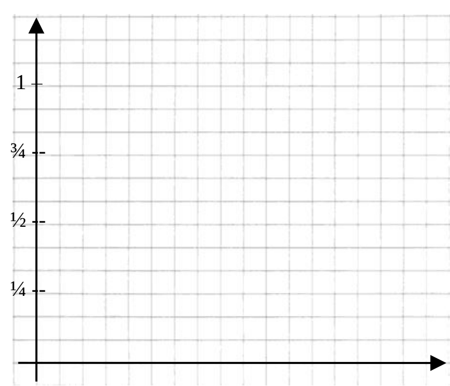
2. Look at the variables in the chart. Which quantity is the dependent variable? Which are possible independent variables?

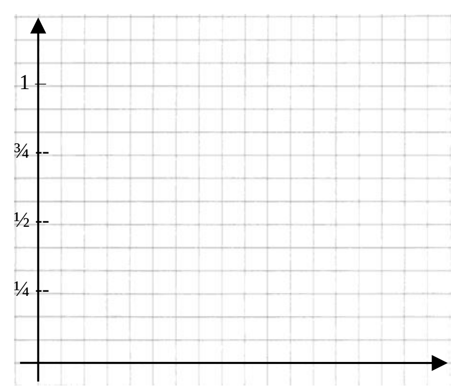
3. The table to the right provides data that resembles what Coulomb might have collected. Let's say you want to find the data that demonstrate how the size of the force is affected by the charge q_2. Explain how you choose this data from the table. Note that all the quantities are measured in generic "units".

Data Set	**Charge q_1**	**Charge q_2**	**Distance r**	**Force Fq_1 on q_2**
1	1	1	1	1
2	½	1	1	1/2
3	¼	1	1	¼
4	1	½	1	½
5	1	¼	1	¼
6	½	½	1	¼
7	¼	¼	1	1/16
8	1	1	2	¼
9	1	1	3	1/9
10	1	1	4	1/16

4. Find patterns in the data and construct three graphs showing how size of the force is affected by the other quantities in this experiment.







5. Describe how the strength of the electrostatic force depends on your chosen variables.

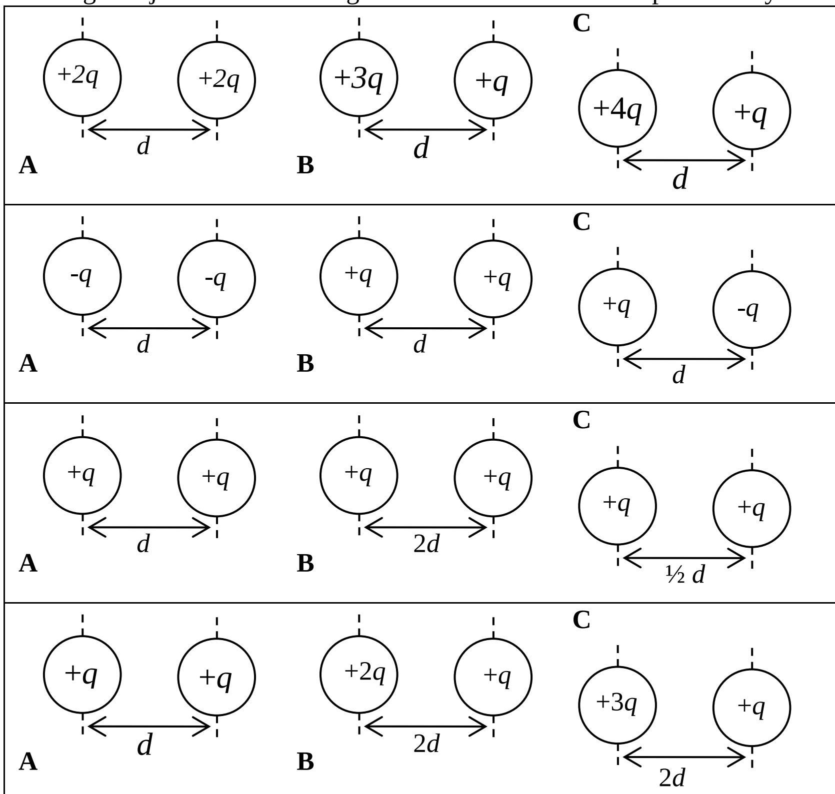
B: Coulomb's Law

Two point-like objects with a net charge exert a force upon one another along a line from the centre of one object to the centre of the other. The magnitude of the electrostatic force that object A, with electric charge q_A, exerts on object B, with electric charge q_B, when they are separated by a center-to-center distance r is given by the expression below. Note that this is also the equal magnitude electric force that object B, with electric charge q_B, exerts on object A, with electric charge q_A:

$$|F_{e\,A-B}| = |F_{e\,B-A}| = \frac{k|q_A||q_B|}{r^2}$$

where $k = 9.0 \times 10^9\ \text{N·m}^2/\text{C}^2$. We assume that the objects are much smaller than their separation r (i.e. point-like objects). The electric charge, q, is measured in units of *coulombs* (C) where 1 C = 6.24×10^{18} electrons or protons.

1. The diagrams show two charged objects and their separation. Rank the size of the force that the left object exerts on the right object from the strongest to the weakest force. Explain how you made the ranking.



Ranking:

Why:

Ranking:

Why:

Ranking:

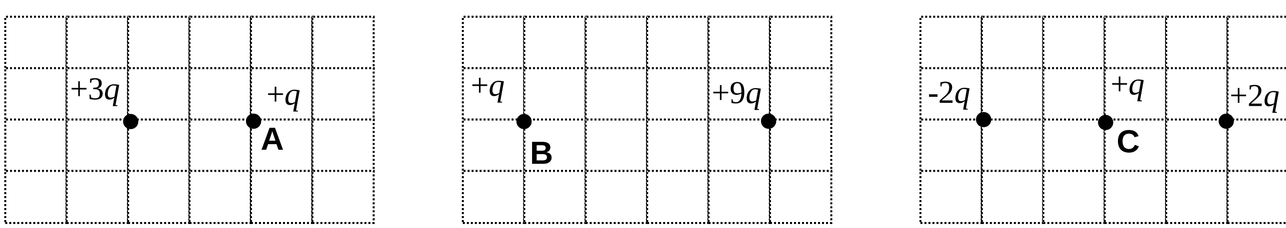
Why:

Ranking:

Why:

2. For each of the cases in the previous activity, compare the force that the left object exerts on the right object to the force that the right object exerts on the left object. Explain how you know.

3. In each diagram below small charged particles are fixed on a grid. All particles have a charge which is a multiple of q. Draw a force diagram for particles A, B and C. Rank the magnitudes of the net electrostatic force experienced by particles A, B and C. Perform a simplified calculation to help explain your ranking.



SPH4U: Analyzing Electrostatic Forces

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

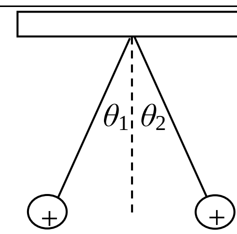
A: Gravity vs. Electricity – Fight!

1. **Represent and Reason**. Imagine two point-like charged objects of mass m_1 and m_2 that have electric charges q_1 and q_2, respectively. Complete the table below that compares their electric and gravitational interactions.

	What property of the objects determines whether they participate in the interaction?	What is the direction of the force between the interacting objects?	Write an expression for the magnitude of the force that one object exerts on the other.	How does the magnitude of the force depend on properties of the objects?	How does the magnitude of the force depend on the distance between the objects?
Gravitational		It is an attractive force.		It is directly proportional to the masses m_1 and m_2.	
Electric	The electric charge determines whether they will interact.				

B: Combinations of Interactions

1. **Represent and Reason.** Two equal-mass stationary spheres are attached to a ceiling by two strings, as shown at the right. The sphere on the left has an electric charge of +5q and the sphere on the right has an electric charge of +1q. Each string makes a **small** angle with respect to the vertical.
   (a) Fill in the tables below.

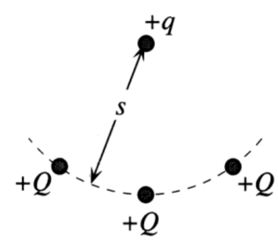


ID	**FD – left sphere**	**FD – right sphere**

Which angle is bigger, θ_1 or θ_2? Explain.	Write down the components for the 2nd law for the right sphere.	Rank the F_T, F_e, and Fg, from largest to smallest. Explain.

(b) The charges on the two spheres are +1 x 10^{-7} C and +5 x 10^{-7} C. Each sphere has a mass of 3.7 g. The two spheres are separated by a distance of 16 cm. What is the angle between the string and the vertical?

2. **Reason.** Three positive charges +Q are placed a distance, s, away from another positive charge +q as shown below. F_e is the strength of the interaction between one charge +Q and +q. Two students discuss the situation:



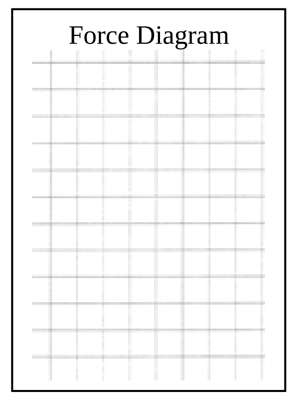
Albert: "*In this situation the net force on the +q charge is three times* F_e, *since there are now three positive charges exerting a force on it*."

Marie: "*I don't think so. The force from the +Q charge on the left will cancel the force from the +Q charge on the right. The net electric force will be the same as the force of one interaction*."

Emmy: *"That doesn't sound right. Maybe it's something in between three times and one times* F_e*."*

(a) Draw a force diagram for the charge q.

(b) Who do you agree with? Explain.



3. **Represent and Solve.** In the previous example the three identical charges were positioned such that there is a 45° angle between adjacent force vectors in the force diagram above.

(a) **Represent.** Write an expression for Newton's 2nd law in the x- and y-directions (only use the symbol F_e). Simplify this expression.

(b) **Solve.** Use the values s = 0.17 m, q = 6 nC, and Q = 3 nC (nC = 10^{-9} C) to find F_e and then the net force.

SPH4U: Introducing … Electric Fields

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

One of the reasons why electrostatic forces seem so mysterious is that they have an effect at a distance, without any objects being in contact. We are familiar with one other force that also has this property.

One way of explaining how gravity can have an effect on objects far away is with the idea of a *field*. We say that Earth has a gravitational field that extends throughout space and that Earth is the *source* of the field. Earth interacts with distant objects *through* its gravitational field.

A: In Search of the Electric Field

For this investigation you will need an electroscope, an ebonite rod, and an acetate strip. An electroscope can be used as an electric field detector. If there is a fairly strong electric field at the location of the metal sphere of the electroscope, the metal leaves inside will repel each other.

1. **Observe.** Charge the rod and move the electroscope in the region of space around the rod. Always be careful with the glass electroscope. Don't let the rod and sphere touch! Describe what you observe.

2. **Reason**. Based on your observations, where is the electric field in that region of space strongest? What happens to its strength further away? What is the source of this field?

The sphere of the electroscope acts as a *test particle* in the rod's electric field. A test particle is a small, point particle whose charge is much less than that of the source. As a result, the presence of the test particle does not affect the field of the source.

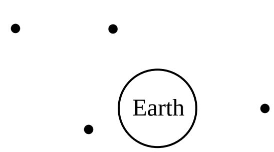
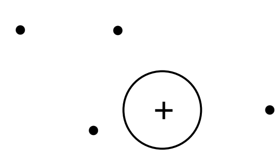
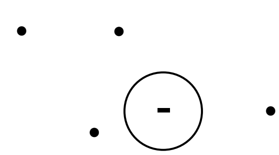
3. **Observe**. (*as a class*) Your teacher has a large electroscope set up at the front of the class. A piece of paper is held just above the electroscope and charged object is brought near the scope, above the paper. Describe what you observe. This is repeated with aluminum foil instead of the paper. Describe what you observe.

4. **Apply.** How would you protect sensitive electronics from unwanted electric fields?

5. **Predict and Test.** What would happen if there is aluminum foil around your cell phone? How many bars do you think you will get? Find a large piece of foil. Try phoning the foiled phone. Describe your observations. Check out the disassembled phones at the front of the class.

B: Picturing the Electric Field

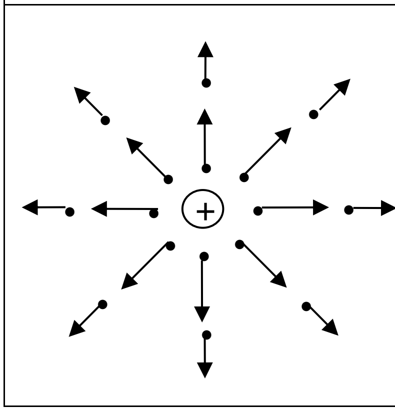
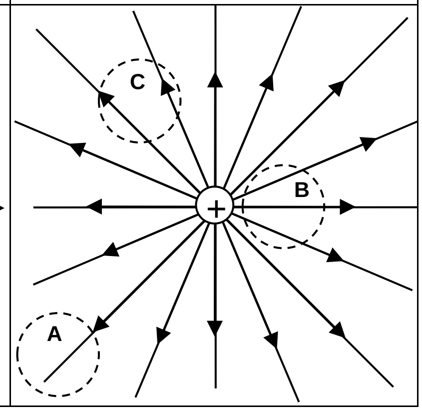
1. **Represent**. For each situation pictured below, draw an arrow for gravitational force or the electric force that a test particle would experience due to the sources at the points shown. When picturing electric fields, we always use **positively charged test particles**.

The planet Earth	An object with a large positive charge	An object with a large negative charge
		

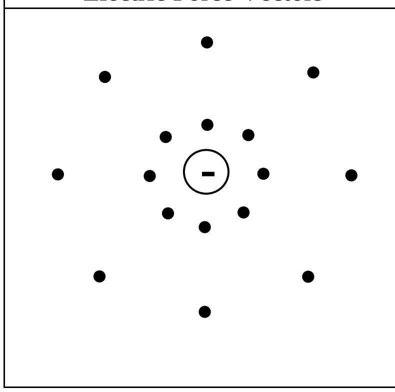
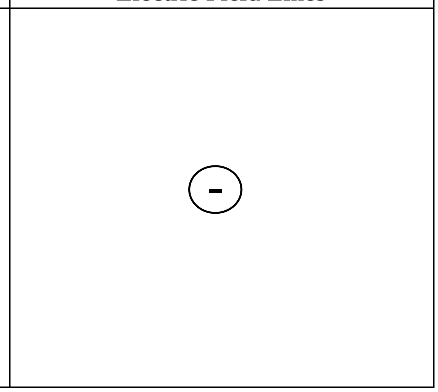
A force field (a field representing forces) is a way of representing the force vectors from an interaction at every point in space. This would require many, many vectors so instead we draw *field lines*. To do this we use a set of rules for **electrostatic** (constant) fields:

(1) The strength of the field at a point is represented by the density or concentration of the lines near that point.
(2) Electrostatic field lines start at positively charged sources and end at negatively charged sources.
(3) The number of lines starting or ending at a charged object is proportional to the magnitude of its electric charge.
(4) Any field line follows the "path" of the vectors. The vector is always tangent to the field line.

2. **Interpret**. The diagrams to the right show the field vectors and field lines for a particle with charge +2 C. Three regions of space are labeled in the field line diagram. Rank the strength of the electric field in each of those regions. Explain how you decide.

Electric Force Vectors	Electric Field Lines
	

3. **Represent.** A new particle is presented with a smaller charge of – 1 C. Explain how the field vector diagram and the field line diagram will be different from the two in the previous question. Draw these diagrams.

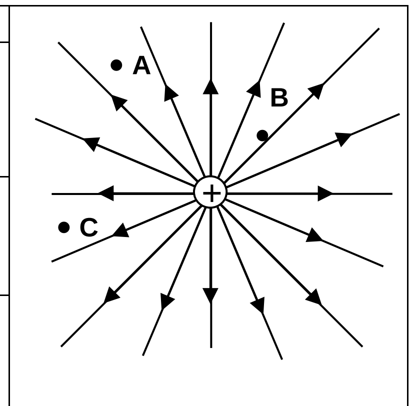
Electric Force Vectors	Electric Field Lines
	

C: Adding Charges to an Existing Field

A common situation we want to explore is what happens when we place a particle with a small charge in the field of a source with a large charge. In this case, we assume that the charge of the particle is very small and does not affect the field of the source.

1. **Represent and Explain.** Draw a vector representing the force acting on each particle placed in this electric field. Imagine you couldn't see the source charge and all you had were the field lines. **Referring only to the field lines**, explain how you decided to draw each vector.

Particle	Charge	Explanation
A	+1 nC	
B	-1 nC	
C	-1 nC	



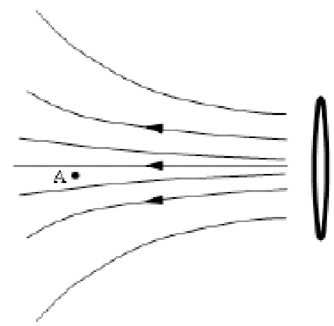
SPH4U: Electric Field Strength

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

The idea of the field is fundamental to modern physics. An object or a system of objects is the *source* of the field. A test object, much smaller than the sources, can be placed in the field without affecting the field. Depending on the properties of the object, it may experience a force from the field due to the sources.

A: It Was a Windy Day

To help us get used to the ideas behind a field, we will think about an analogy with wind. A very large, industrial strength fan creates a wind pattern as shown in the diagram to the right. Someone holds a small kite at point A. Then the person holds a larger kite at that same point. In both cases, the kite directly faces the fan and therefore catches the wind.



1. **Reason.** In what sense is the wind stronger on the large kite than it is on the small kite?

2. **Reason.** In what sense is the wind equally strong at both kites? What could you measure about the wind to illustrate this point?

As a convenient catchphrase, let's define the *wind field* as the strength and direction of the wind itself at a given point (whether or not an object is held there). So, the wind field at point A stays the same whichever kite you put there; but that same wind field produces a different wind force on kites of different sizes. Now you'll figure out a way to define the wind field more precisely.

3. **Reason.** The smaller kite has cross-sectional area 0.50 m^2. When held at point A, it feels a wind force of 3.0 N. The larger kite has exactly twice the cross-sectional area (1.0 m^2) of the smaller kite. What wind force would you expect the larger kite feel at point A? Explain.

4. **Reason.** Now a kite of cross-sectional area 2.0 m^2 is held at point A. What wind force do you expect it to feel? Why? Complete the chart showing all your results and describe the pattern.

Surface Area (m^2)	Force (N)
0.50 m^2	3.0 N
1.0 m^2	
2.0 m^2	

5. **Evaluate.** Below are two possible mathematical definitions of a wind field. Which of these, if either, better captures the pattern you found above? Comment on the validity of each one.

wind field = wind force × cross-sectional area	wind field = wind force ÷ cross-sectional area

6. **Reason**. Based on the better definition you found above, what is the value of the wind field at point A (including units)?

Adapted 2015 by C. Meyer from *Tutorials in Physics Sense-Making,* University of Maryland Physics Education Research Group

7. **Summarize**. Does the wind force depend on the fan, the kite, or both? What about the wind field? Explain.

The wind force depends on…

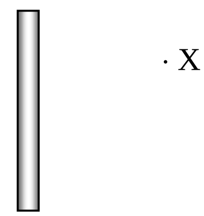
The wind field depends on…

*** call your teacher over to check your results ***

gB: The Electric Field

We just saw that the wind field is the strength and direction of the wind, independent of whether the wind acts on anything. In general, a field is the strength and direction of something, independent of whether that something acts on an object. Let's apply these ideas to electric fields.

An ebonite rod is given a charge by rubbing it with acetate. You hold a particle with a small charge at point X. Then you pull it away and hold a particle with a larger charge at that same point.



1. **Reason.** When we place a particle with a greater charge at the same position near the rod it experiences a greater "effect". Does that "effect" correspond to a larger electric force, a larger electric field, or both? What law explains this greater effect?

2. **Reason.** There is another sense in which both particles feel the same "electric effect" at point X. Does that sense correspond to the same electric force, the same electric field, or both? Explain.

3. **Reason.** As we saw with kites, the property of an object that determines how much it responds to a given wind field is its cross-sectional area. What property of an object determines how much it responds (how much force it feels) to a given electric field?

4. **Summarize.** Does the electric field experienced by a particle at point X depend on the charge of the rod, the charge of the particle or both? Explain.

The Field Assumption: When we work with fields, we will assume the charge of the source of the field is much greater than the charge of the test particles we place in the field. If this assumption is valid, we can say that the source *produces* the field and the field of the test particle is so small that it can be ignored. If this assumption is not valid, then we must consider multiple charged objects as the sources of the field.

C: Defining the Electric Field

When held at point X, a particle of charge 2.0 nC (nanocoulombs, n = 10^{-9}) is repelled by the rod with a force of 0.1 N. The charge on that particle is now doubled, to 4.0 nC, and the particle is again held at point X.

1. **Reason.** What force do you expect the particle now feels from the rod? Explain.

2. **Reason.** Now a particle of charge 8.0 nC is held at X. What electric force do you expect it feels from the rod? Complete the chart for all your force and charge values.

Charge (nC)	Force (N)

3. **Reason.** So, the three particles feel different electric forces at point X. But the electric field at X is the same no matter which particle you hold there (just like the wind field). Use the values in your chart to find one value for the strength of the electric field at point X.

4. **Reason.** Let's explore the meaning of the field value you came up with. What are the units of that number? Explain what that number means, and why it corresponds to the notion of electric field.

5. **Reason.** You'll now "translate" these concepts into an equation. Let E denote the electric field created by a rod or other collection of charges; let q denote the charge of a particle placed in the field; and let F_e denote the electric force felt by that particle. The symbol for the electric field is E, but we will write a "curly E" ε to avoid confusion with the symbol for energy. Write an equation relating $\mathcal{E}$, q, and F_e.

*** call your teacher to check your results ***

5. **Summarize.** Now let's compare three similar examples of fields: wind, gravitational and electric. Summarize the comparisons in the chart below.

	Wind strength	Gravitational field strength	Electric field strength
Property of an object that determines how much force it experiences.			
Units of field			

Definition of the Electric Field.

An electrostatic field describes the electrical effects throughout space of a charged source object *S* on a charged test particle *T*. A test particle is any object whose electric charge is much smaller than that of the source. If this is true ($q_T << q_S$) then we say that the source object creates the electric field and the test object experiences that field.

The strength and direction of the electric field depend on only the charges of the source and the position in space. To measure the electric field strength we need to use a charged test particle *T*. The electric field strength due to a source *S* at a point in space (for example, 10 N/C) means that if we place test particle *T* at that position, it will experience 10 N of force for each coulomb of its charge, q_T.

Gr. 12 version: $$\varepsilon = \frac{F_{e\,S-T}}{|q_T|}$$

Pro Version: $$\vec{E} = \frac{\vec{F}_{e\ S-T}}{q_T}$$

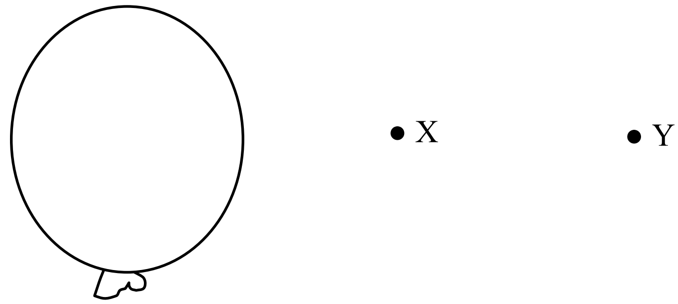
Use the gr. 12 version of the equation to find the strength of the electric field. Use diagrams and your understanding of fields to reason about the directions. Use a sign convention to show the directions, just like you do with forces, when using Newton's 2nd law.

SPH4U: Field Concept Homework

You rub a balloon against your head giving the balloon a large negative charge of $q_{\text{balloon}} = -6.3\text{x}10^{-7}$ C. The balloon is now the source for an electric field. Two points in space are labeled: point X which is 5 cm away from the balloon and point Y which is 10 cm away. We will use two different test particles to explore the balloon's electric field. Particle A has a charge $q_A = +2.5 \times 10^{-10}$ C and particle B has a charge of $q_B = +5.0 \times 10^{-10}$ C.

1. **Represent.** Draw a charge diagram for the balloon using the illustration to the right.

2. **Reason**. We place particle A at point X as part of our first experiment. Rewrite the equation for the electric field: $\varepsilon = \frac{F_{e\,S-T}}{|q_T|}$ using the subscripts appropriate for the objects in this situation. Explain how you decided which charge goes in the denominator of this expression.



3. **Calculate.** At position X, we measure an electrostatic force of $1.8\text{x}10^{-5}$ N acting on particle A. What is the size **and** direction of the electric field particle A experiences at that point?

4. **Reason.** Next we place particle B at point X. How does the size of the electrostatic force on particle B compare with particle A? How does the size of the electric field particle B experiences at that point compare with particle A?

5. **Reason.** Now we place particle A at point Y. How does the electrostatic force on particle A at point Y compare with point X? How does the electric field strength at point Y compare with point X? Explain and be as precise as possible.

6. **Calculate.** You place a new and mysterious test particle at point X and observe that it experiences an electrostatic force of 2.1×10^{-5} N in a direction away from the balloon. What is the charge of this mysterious particle?

7. **Reason**. When the source of an electric field is spherical, or a point particle, we can find the strength of the electrostatic interaction using Coulomb's Law. Use Coulomb's Law and the definition equation for electric fields to find a **simplified** expression for the electric field strength around a spherical source object with charge q_S using a test particle with charge q_T.

SPH[redacted]th Multiple Sources

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

A: Two Sources and Only One Field, Ja!

This is a class demonstration that your teacher will lead.

1. **Observe**. (*as a class)* Rub the acetate against paper and hold the negatively charged acetate near the electroscope. Remove the acetate and hold the paper near the electroscope. Describe your observations.

2. **Reason.** (*as a group)* Is there anything different about what's happening to the charges inside the electroscope when the acetate or paper is brought near? Explain.

3. **Predict**. (*individually)* Your teacher will hold the freshly rubbed paper very close to the electroscope. Then, starting from far away, slowly bring the acetate close. What will initially happen to the electroscope leaves as the acetate gets closer?

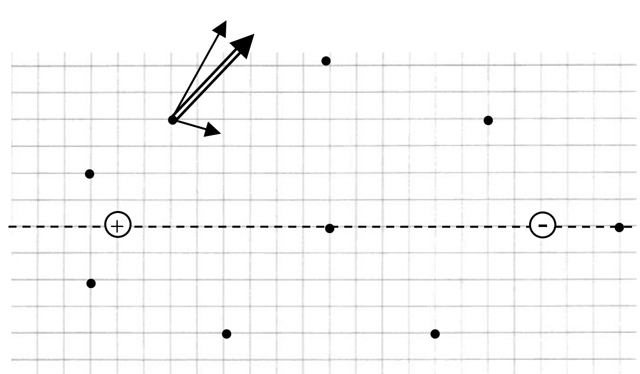
4. **Observe and Reason**. (*as a class)* Observe as the paper and then acetate are brought close to the electroscope. What can we say about the net force on the charges of the electroscope? What is the strength of the electric field at that position in space? Explain.

The electric forces from multiple sources add and give a total electric force (kind of like a net force for just electrostatic interactions). We will re-interpret the defining equation for the electric field. $F_{e\,S\text{-}T}$ is the *total* electric force from all the source objects acting on the test object. $\varepsilon = \frac{F_{e\,S-T}}{|q_T|}$

B: Opposites Attract

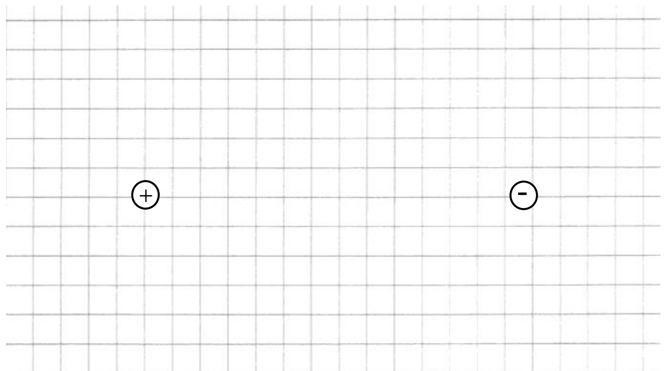
Imagine that we position two equal but opposite charges along a line. This configuration is called an *electric dipole*.

1. **Represent and Reason**. Imagine we place a small test particle with positive charge at each of the points shown in the diagram below. Draw a force diagram at each point for the electric forces due to the individual sources (just estimate their magnitudes and use a ruler to help with the directions). With a different colour, draw a vector to represent the total electric force at each point (if you are familiar, use the parallelogram trick!).



Remember our rules for electrostatic fields:
(1) Any field line follows the "path" of the vectors. The vector is always tangent to the field line.
(2) Electrostatic field lines start at positively charged objects and end at negatively charged objects.
(3) The strength of the field at a point is represented by the density or concentration of the lines near that point.
(4) The number of lines starting or ending at a charged object is proportional to the magnitude of its electric charge.

2. **Predict.** Review the rules for electric field lines. Use the net field vectors you found to help trace **a few field lines** for the two charges on the grid below. Don't draw any vectors!



3. **Observe.** Use the applet: http://www.falstad.com/vector3de/. It should work on most phones. Select "dipole" for the field selection and select "Display: Field Lines". Select "Show Y Slice". Make any changes to your prediction if necessary.

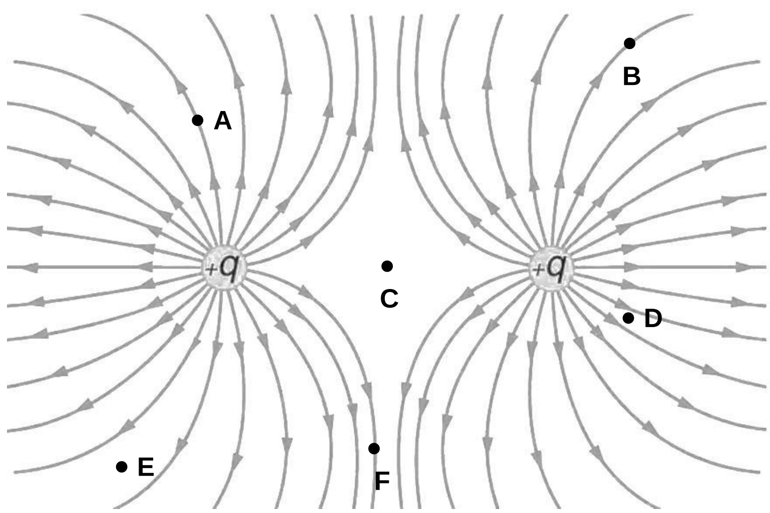
4. **Apply**. What are some realistic examples of systems with the field of a dipole (think of chemistry examples!)

5. **Predict**. What will happen to the net electric field if the distance between the positive and negative sources becomes very small (small enough we can't notice it)? Explain your prediction.

6. **Test**. Test your prediction using the simulation. Gradually decrease the charge separation and describe what happens to the total field. What is a realistic example of a system like this?

C: Opposites Attract, Likes …

Two positively charged sources produce the electric field shown below. Charged particles are placed at each labeled point.



1. **Reason.** At which point is the electric field the strongest? At which point is it the weakest? Explain.

2. **Represent.** Particles A, B and C have identical positive charges. Particles D, E, and F have identical negative charges. Draw an electric force vector for each particle.

3. **Reason.** Isaac asks, "Why doesn't the electric

force vector for particle F point at any of the sources of the field? This seems strange.” Use a force diagram to help explain why.

SPH4U: Moving Charges in a Uniform Field

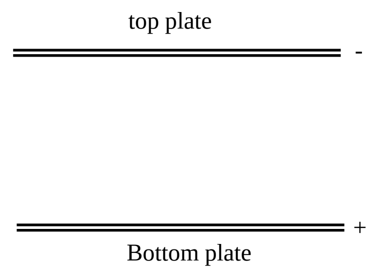
Recorder: ________________
Manager: ________________
Speaker: ________________
0 1 2 3 4 5

Aside from particles accelerating due to gravity, pretty much all other particle motion that we experience can ultimately be explained (usually at a microscopic level) by electric fields. This is especially important in the areas of molecular biology and chemistry where electric fields rule the day and explain **everything** that happens.

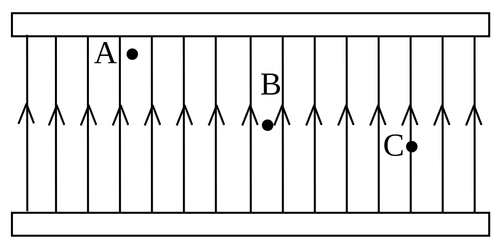
A: Charged Plates

An important electrostatic field is the one that exists between two parallel metal plates that have opposite electric charges. This type of field is a good model for the fields present in old cathode ray tube TVs, in the massive particle accelerator at CERN, or a cell membrane.

1. **Observe**. (*as a class)* Draw the field lines for parallel plates based on the simulation. How do the directions of the field lines near the middle of the plate compare with one another?



2. **Interpret**. An idealized field between two oppositely charged parallel plates is **uniform**, as shown in the diagram to the right. This is the field we will consider when working with parallel plates.
   (a) **Explain.** What does the word “uniform” mean when we say that the field between the plates is uniform.



   (b) **Reason.** Identical test particles are placed at points A, B, and C. Rank the size of the force each particle experiences. Explain your ranking.

B: The Moving Through the Field

What happens when a particle is free to move in a uniform electric field? Let’s find out!

1. **Reason.** A positively charged particle is placed at point A in the field shown above. A negatively charged particle is placed at point C. Suppose all you have are the field lines from the diagram above. Is that enough to figure out the direction of the force experienced by each particle? Explain. Draw a force diagram for each particle.

2. **Represent and Explain.** An electron is at rest at point B and is released. Draw a motion diagram for the particle after its release. Describe how it moves and explain why.

3. **Represent.** An electron is launched horizontally from point A. Draw a motion diagram for the particle after its release. Describe the motion of the particle.

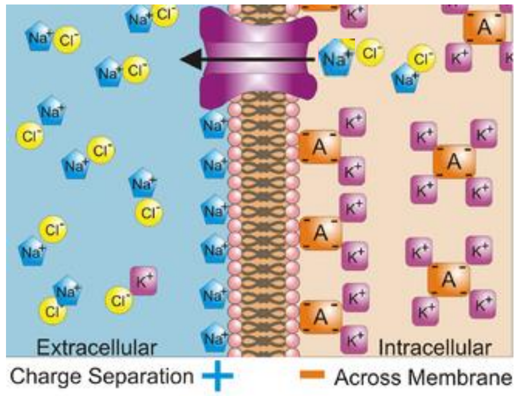
*** Check your results using your teacher's simulation***

The strength of the electric field (the total field) between two oppositely charged parallel plates de

applied across the plates and the distance between the plates. $\mathcal{E} = |\Delta V|/d$, where V/m is another valid set of units for electric field strength.

C: The Cell Membrane – Field Work

As you read this, millions of neurons in your brain are firing electrical signals. This process occurs due to the transport of ions (charged particles!) across the cellular membranes of neurons. In preparation for firing, neurons build up a concentration of ions on opposite sides of the cell membrane using proteins that pump sodium ions out of the cell. This creates an electric field across the membrane and the neuron's *resting potential*.



Cell membrane

1. **Represent.** Draw the charge build up on the two outer surfaces of the cell membrane. (Use a "+" for a positive ion and use a "-" for a negative ion.) Draw the electric field lines in between the layers.

The resting potential (the voltage) has a value of -70 mV (m = 10^{-3}) across a membrane that is 8 nm (n = 10^{-9}) thick. The ion has a mass of 3.818 x 10^{-26} kg and a charge of 1.602 x 10^{-19} C.

2. **Calculate.** What is the minimum force the protein must exert to move the sodium ion against the electric field and out of the cell? How much work does the protein do? (Hint: try using energy to solve this problem!)

D: Mathematical Representation

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

3. **Evaluate.** The energy source for the protein pump is ATP. During ATP hydrolysis, each molecule of ATP can provide roughly 5×10^{-20} J of useful energy. Biologists believe that one ATP is needed to pump one sodium ion across the cell membrane. Does this seem reasonable?

SPH4U: Magnetostatic Fields

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

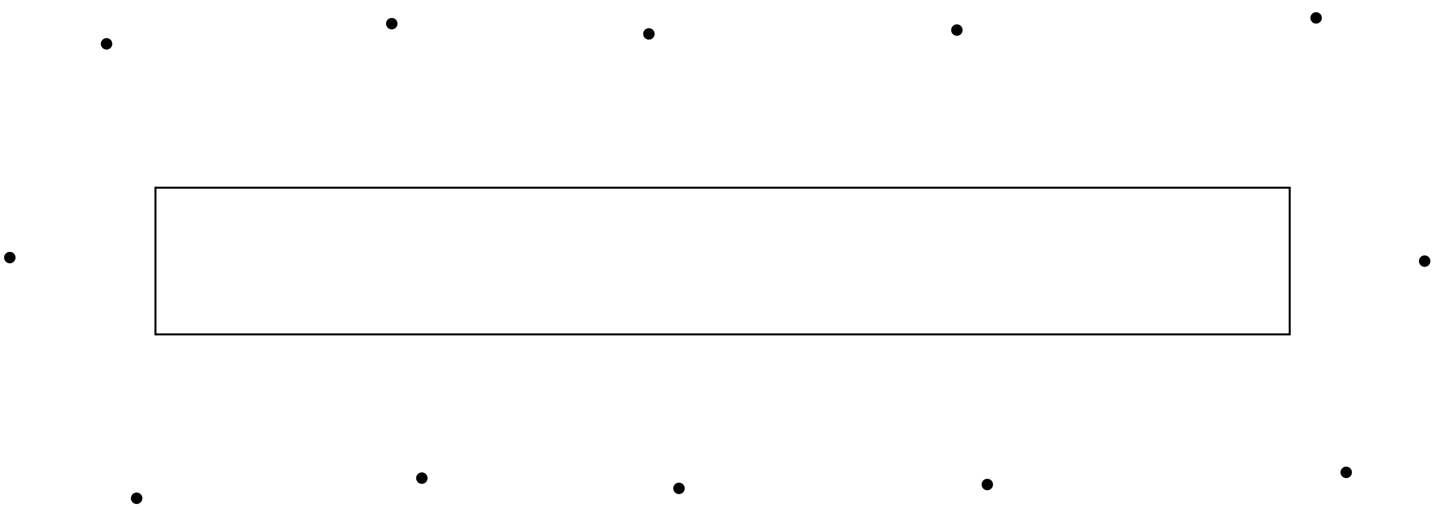
Fields can describe the force of any interaction that has an effect throughout space. Another force you have no doubt played with is magnetism. We need to develop some new rules and ideas to describe magnetic effects. For example, with magnetism we won't use test particles we will use test-compasses!

A: Searching for a Field

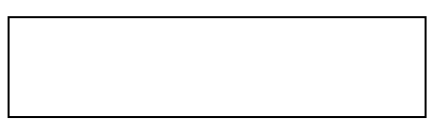
You need a bar magnet and a compass.

A compass is a tiny bar magnet. The direction the north end of a compass points defines the direction of the magnetic field at that position in space. Always check that your compass works properly – it should jiggle at the slightest touch and the coloured end should point north.

1. **Observe.** Place the compass at each point in the region around the bar magnet as shown below. Draw an arrow showing the magnetic field vector ($\vec{B}$) at that position in space.



2. **Observe**. Use the applet: http://falstad.com/vector3dm/. Set the field selection to "solenoid". Set the display to "Field Vectors" and then "Field Lines". It may be easier to see if you choose "Show Y Slice". We can't examine the field inside the bar magnet with a compass, but we can study it using a solenoid. A solenoid is a coil of wire whose field is very similar to that of a bar magnet. Sketch the magnetic field lines around and **inside** the bar magnet. Add arrows to the field lines to match your field vectors above.

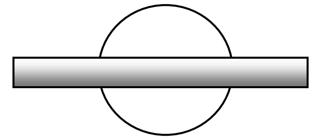


3. **Explain**. Point out regions where the field strength is particularly strong and weak. How can you tell?

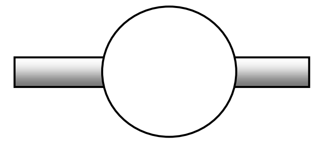
B: The Birds and the Bees of Magnetism

You need an alligator wire, a compass and a 9V battery. WARNING: Never clip both ends of the [illegible] will overheat!

1. **Observe.** Place the wire over the top of the compass such that it is parallel to the needle. Clip one end of the wire on the battery. Briefly touch the second alligator clip to the other battery terminal – DO NOT CLIP IT ON! **Hold the wire in place only long enough for the needle to stabilize**. Record your observations. Illustrate the direction of the electron current flow and the compass needle. Is there any evidence for the existence of a new magnetic field?



2. **Observe**. Now hold the compass just above the wire. Repeat your observations.



3. **Observe.** Clip only one end of the wire to the battery. Move the middle of the wire above the compass. Describe your observations. Is there any evidence for a magnetic interaction between the compass and the wire?

Magnetic fields ($\vec{B}$) are created by **moving** electric charges. Charges at rest (static charges) **do not** create magnetic fields. To illustrate the motion of the charges and the magnetic fields, we need a new set of symbols. For a vector pointing out of a page draw: ⊙ For a vector pointing into a page draw: ⊗

The *Left Hand Rule for the Magnetic Field of an Electron Current* relates the motion of negatively charged particles to the magnetic field they create. When the thumb of your left hand points in the direction of the electron current, your fingers curl in the direction of the magnetic field lines.

Field Vectors

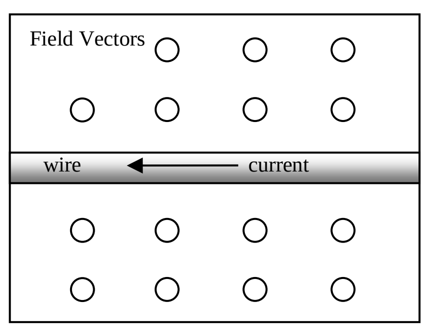
4. **Observe and Explain**. Use the applet: http://falstad.com/vector3dm (should work on most phones). Set the field selection to "current line". Set the display to "Field Vectors". Select "Show Z Slice". Sketch a sample of the field vectors around the wire. Is the current flowing into or out of the page? Does this representation agree with your compass observations? Use the left hand rule to help explain.

***Note – this applet defaults to conventional current flow. When opened in some browsers (ie: Chrome), you will see a "reverse" checkbox to change to electron flow, which is what we use in class.*

Field Lines

5. **Observe**. Now set the display to "field lines". Sketch the field lines and the current in the box to the right. Which way should the arrows on the field lines point? Now draw them!

6. **Predict** Imagine the wire is oriented across our page as shown below. It is difficult to draw the field from this point of view. We can simply show the direction of the field vectors as they pass through the page surface. Explain whether the field vectors will point into or out of the page in the region around the wire.



7. **Test.** Switch back to field vectors and choose "Show X Slice". You may need to rotate the image to understand what you are seeing. Explain any differences with your prediction. Draw field vectors illustrating your observations using ⊙ and ⊗.

SPH4U: Magnetic Forces on Charges

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

A: Charges at Rest

This is a class demonstration. We want to study the interaction between a magnetic field and a charged object that is stationary. An electromagnet will create the magnetic field and rubbing a balloon will create a static electric charge.

1. **Observe.** For each situation, record your observations in the chart below.

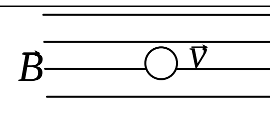
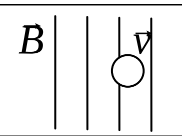
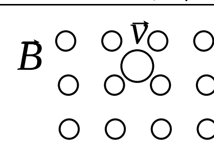
Charged balloon, magnet turned on	Charged balloon, magnet current reversed	Charged balloon, magnet turned off

2. **Reason**. Is there any evidence from your observations for the existence of a magnetic interaction between a charged object at rest and a magnetic field? Justify your answer using your observations. *Record your decision on a whiteboard.*

B: Charges on the Move

This is a class demonstration. We want to study the interaction between a magnetic field and moving charges. An oscilloscope tube and high tension power supply will produce beam of electrons. A permanent magnet will provide the magnetic field. We will explore three situations with electrons moving through a magnetic field.

1. **Observe and Represent**. Record your observations and complete a representation showing the velocity of the electrons, the magnetic field and the force acting on the charges.

Situation	Observations	Representation
The bar magnet is held perpendicular to the beam with the north pole beside the tube. To a good approximation the magnetic field points straight out from the end of the bar magnet.		
The bar magnet is held perpendicular to the beam with the north pole above the tube.		
The bar magnet is held parallel to the tube with the north pole pointing towards you.		

2. **Reason**. (*as a group*) Two conditions must be met in order for magnetic fields to exert a force on a charged object. From your observations in parts A and B, what are these two conditions?

The force that results from the movement of a charged object in a magnetic field is given by: $F_m = |q||v||B|\sin\theta$, where q and v are the charge and speed of the object, B is the strength of the magnetic field the object is moving through and θ is the angle between the magnetic field lines and the velocity. The direction of the force is determined by the *Left Hand Rule for the Magnetic Force on Negative Charges*: The thumb points in the direction of the velocity of the charged object, the fingers in the direction of the magnetic field lines. The palm of your hand points in the direction of the force on a negatively charged particle. If the object has a **positive** charge, just reverse you answer from the left-hand rule.

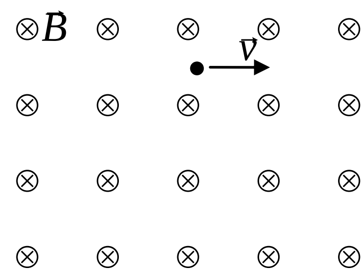
3. **Reason.** Use the equation for the magnetic force to verify your conditions from the previous question. Explain.

4. **Predict**. Use the left hand rule to predict how the beam will deflect when the bar magnet is held perpendicular to the beam with the **south** pole on the left side of the tube. Draw a picture to illustrate your prediction. We will try this out as a class. Move on for now.

prediction

C: The Motion of Charges in a Magnetic Field

Consider an electron traveling with an initial velocity *v* moving through a magnetic field that is oriented into the page as shown to the right.



1. **Reason**. What is the direction of the force acting on the electron? Explain and draw the force on the diagram.

2. **Reason**. A short while later, where might the electron be located? Draw it and its new velocity vector. At this later moment, what will the direction of the force be? Draw this on the diagram. Explain.

3. **Predict**. Assume the electron never leaves the magnetic field. What will the complete path of the electron look like? How will the directions of the velocity and force vectors compare? What type of motion results? Explain.

4. **Reason**. How much work does the magnetic field do on the electron? How does the electron's speed and kinetic energy change? Explain.

D: The Sun Sneezes, We Get Northern Lights

Our sun is constantly belching out protons that travel to Earth and encounter Earth's magnetic field. These particles can become "trapped" in the field when they start to travel in circles due to the magnetic forces! According to NASA, the solar protons reach Earth with a speed of about 400 km/s. High up in the atmosphere the protons encounter Earth's magnetic field that has a strength of 1.2×10^{-5} T. (The unit for magnetic field strength (B) is the tesla, T.) The angle between the magnetic field and the velocity of the protons is 90^{o}. What is the frequency at which these protons circle?

D: Mathematical Representation

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

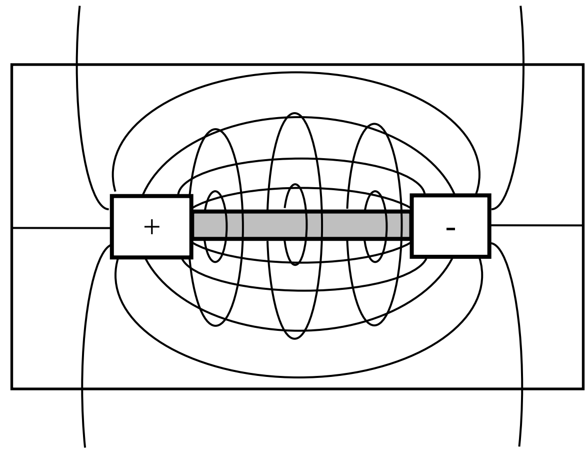
SPH4U: Electromagnetic Disturbances

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

We have studied both electro- and magneto-static fields up to this point. Now we will combine these fields and begin to change them so they are no longer static. Something truly remarkable happens.

A: The Physics of a Wire

Consider a wire connected between the negative and positive terminals of a power supply. A steady current travels through the wire. The diagram to the right illustrates this situation and shows two sets of field lines.



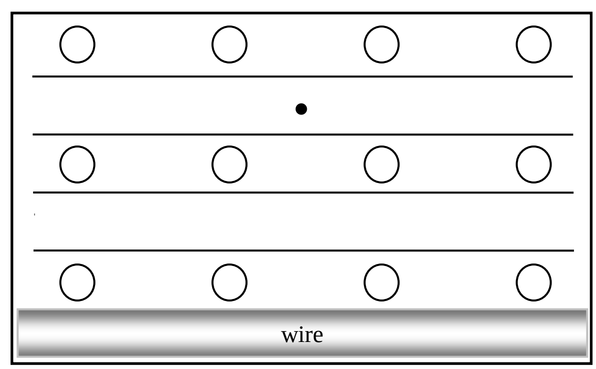
1. **Represent.** Choose a colour to represent the electron current. Draw an arrow that represents the flow of electron current.

2. **Represent and Explain.** Choose a colour to represent the electric field. Explain how you decide which lines are the electric field lines. Label and colour code these lines. Add arrows showing the direction of the field lines.

3. **Represent and Explain.** Choose a colour to represent the magnetic field. Explain how you decide (as if you haven't done question #2) which lines are the magnetic field lines.

B: A Closer Look

Now imagine that we zoom in to a small region of space located above the middle of the wire. The diagram below illustrates this along with the electric and magnetic field lines. Note that one field points in or out of the page and is represented with the circles.



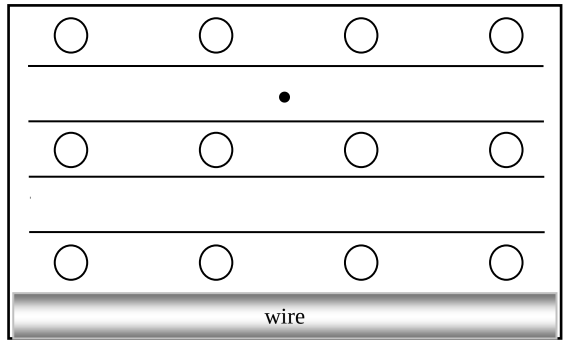
1. **Represent.** Complete the diagram by: (a) labeling and colour coding the electric and magnetic field lines and (b) showing the direction of all the field lines and current

2. **Reason.** How do the directions of the electric and magnetic field lines compare in this region of space?

3. **Explain.** A positive test charge • is placed at rest in this region of space. In this investigation**, we will ignore the effects of the magnetic field since they are relatively small**. What will happen to the positive charge which is initially is at rest? Explain and draw vectors representing any forces.

Below is a third diagram showing the same region of space as above. But for this example, we have switched the polarity of the power supply, reversing the positive and negative terminals shown in the first diagram.

4. **Represent and Explain.** Complete the diagram as you did in question #4. Describe the how the fields have changed due to the reversed terminals.



5. **Explain.** What will happen to the positive test charge which is initially at rest?

C: Shaking Things Up

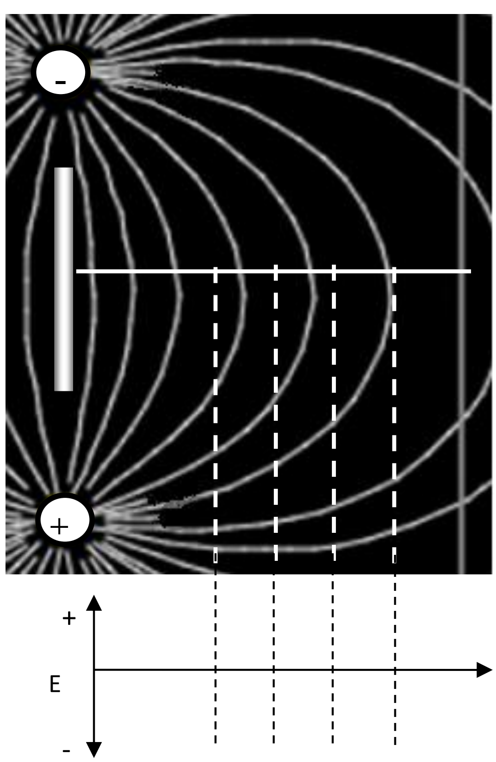
Now imagine that we continuously vary the polarity of each terminal of the wire from positive to negative.

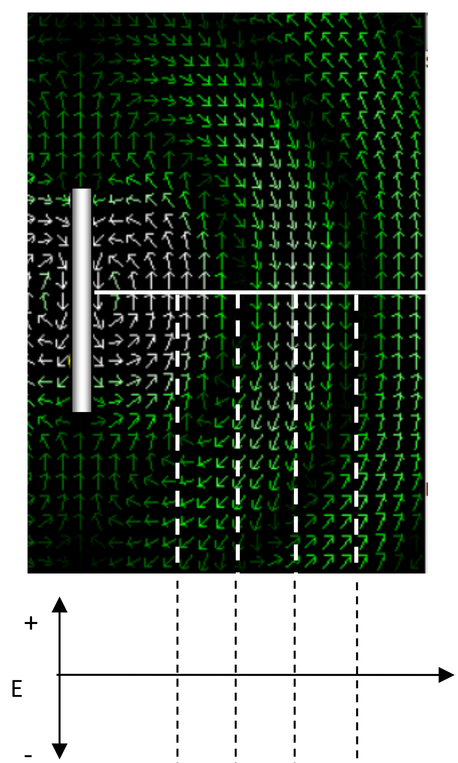
6. **Reason.** Describe the motion of the charges in the wire.

7. **Reason.** Describe the motion of the positive test charge as the polarity varies.

8. **Observe.** When the polarity of the wire changes, the fields don't change everywhere immediately. They begin to change closest to the wire and then spread outwards through space. Use the simulation: http://falstad.com/emwave1. Describe what this changing pattern looks like.

9. **Compare.** Here are images showing an electrostatic field along with the simulation above (but the magnetic fields have been removed). Interpret how field strength and direction is represented in each image. Use the images to sketch what happens to the electric field strength and direction as you move further away from the source along a particular line.





10. **Observe.** Freeze the simulation. Electrostatic or magnetostatic fields drop off in a steady way (further from the source, the field always become smaller) at positions farther from the sources. Is this happening in this situation? Explain.

An alternating current produces a changing pattern of electric and magnetic fields that spreads outwards from the wire through space. In 1864, James Clerk Maxwell studied these phenomena in detail and mathematically described the wave-like motion of these oscillating fields. From his calculations he determined the outwards speed of the rippling fields to be given by:

$$v^2 = \frac{4\pi k}{\mu_o}$$

Where k is Coulomb's constant (k = 8.99 x 10^9 Nm^2/C^2) and μ_o is a similar constant for magnetism (μ_o = 1.257 x 10^{-6} Tm/A).

11. **Predict.** Determine the velocity of this wave including units (1A = 1C/s) (1T = 1 kg/Cs). What are the implications of this result?

Rules for Electromagnetic Waves.
What we have discovered is an electromagnetic wave which works according to these ideas:
1) An EM wave is created by the acceleration of electrical charges (our varying current in this case).
2) An EM wave might cause a distant charged particle to acceleration if the properties of the wave match properties of the particle.
3) When an EM wave accelerates a charged particle, some of the wave's energy is absorbed which might stop the wave.

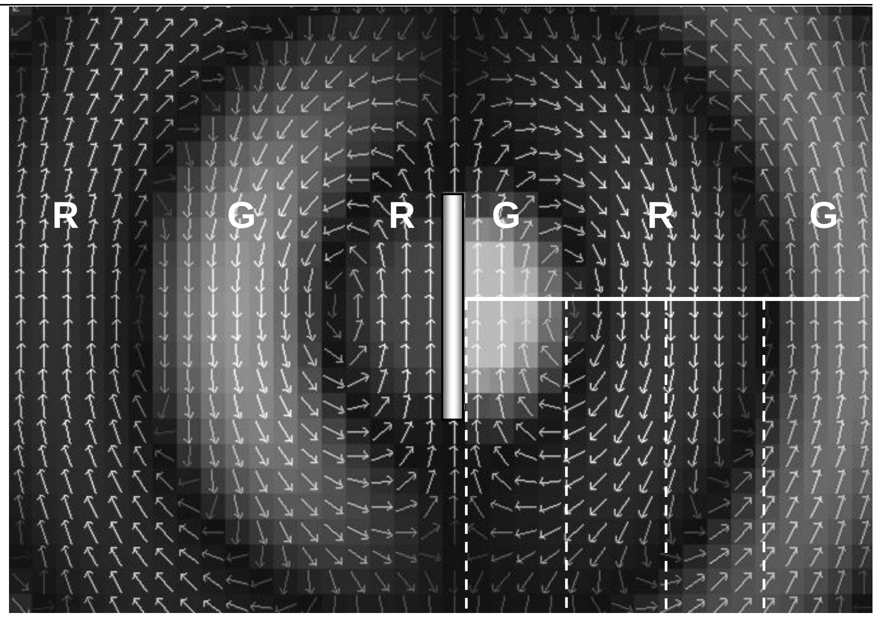
SPH4U: Understanding EM Waves

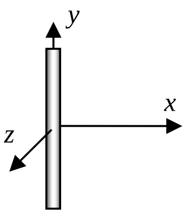
Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

A genuine, real-life EM wave is very tricky to visualize – it has much more detail than a simple water wave. To help us picture what takes place when an EM wave travels through space we will use the *line model* of an EM wave.

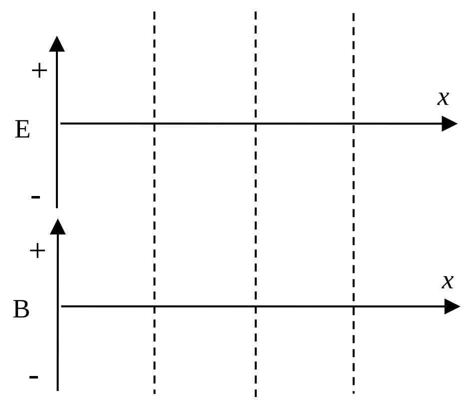
A: The Line Model of an Electromagnetic Wave

To the rightis a screen capture from the simulation we used in our previous investigation. It represents a two-dimensional slice in space and the field values along that slice. To help us talk about this image we will define the vertical direction as the *y*-direction and the *x*- and *z*-directions as the horizontal plane. The wire is positioned along the *y*-axis with its middle at the origin. This image represents the field values in the *xy*-plane.



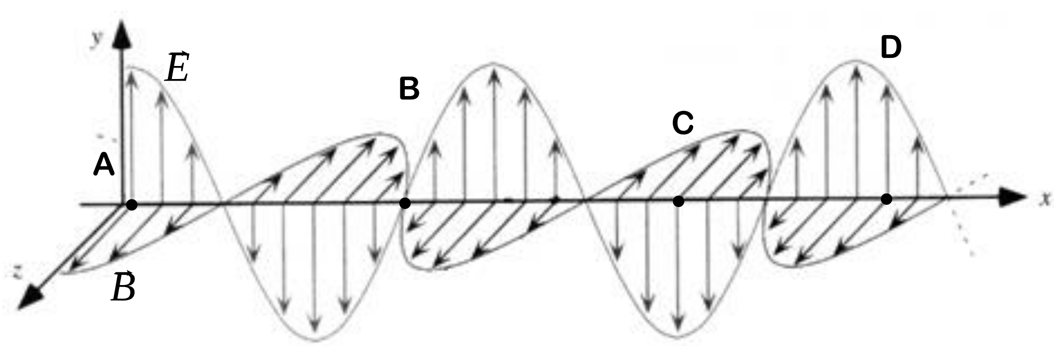


1. **Represent.** Imagine we draw a line along the *x*-axis starting at the surface of the wire. **Remember** that the simulation does not show the field strength using the arrow lengths. Sketch a graph of the electric field vs. position along the +*x*-axis (the white line). Do the same for the magnetic field. Upwards is positive for the $\mathcal{E}$-field and outwards (green) is positive for the B-field.



We can put these two graphs together and illustrate the field vectors to give us the *line model* of an electromagnetic wave. This is a picture of the electric and magnetic field vectors along one line through space at one moment in time. One extraordinary feature of an EM wave is the fact that the amplitude of the peaks decreases very, very little allowing EM waves to travel extremely far through space - even across the entire universe!

2. **Reason**. Examine the line model of an EM wave shown to the right. Rank the **magnitude** of the electric field at points A, B, C and D in space. Explain.



3. **Reason.** In what direction is the EM-wave propagating (travelling)? Draw an arrow on the diagram above.

4. **Reason**. How do the directions of the electric and magnetic fields compare with the direction of propagation?

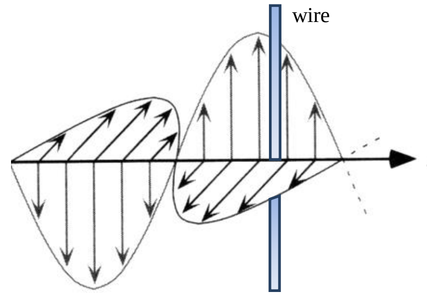
5. **Reason.** An electron is located at point C in the diagram above and is at rest. In what direction will it experience a force?

In this example, we noticed that along the line through space that we chose, the electric field vectors point along one axis (the *y*-axis in this case). An electromagnetic wave with its electric field vectors pointing along one axis in space is a *linearly polarized* EM wave. We call the direction the electric field points in the *direction of polarization* of the EM wave.

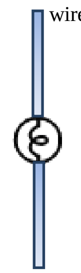
B: Wave, Meet Conductor. Conductor, Meet Wave.

Imagine that the EM wave depicted above in question #2 is a radio wave. It is polarized in the *y*-direction. As it travels outwards, it passes by a long, thin conducting wire that is oriented along the *y*-axis.

1. **Reason.** As the wave propagates (travels) past the wire, would the electric field due to the radio wave cause the charges in the wire to move? If so, would the charges move in a direction along the wire? Explain.



2. **Reason.** Imagine a very sensitive light bulb is connected to two halves of the same wire in the middle. The bulb and wire are again placed in the path of the previous radio wave and with the wire oriented parallel to the *y*-axis. Would the bulb glow? Explain.



3. **Reason.** Would it glow if the wire was oriented parallel to the *z*-axis? Explain.

4. **Reason.** Would it glow if the wire was oriented parallel to the *x*-axis? Explain.

An antenna is a conductor designed to capture the energy from an electromagnetic wave. The electric field of the wave causes charges in the antenna to accelerate, transferring electromagnetic energy from the wave into kinetic energy of the moving charges. An electric current is created or *induced* and this current can be used in an electric circuit to do many things! We say the EM wave is the *signal* which is picked up by the antenna and used by the circuit. This is how a radio station signal, a Bluetooth signal, a Wi-Fi signal, a TV signal, and a cellphone signal all work!

5. **Predict.** In order to best detect the oncoming radio wave (that is, to maximize the induced current in the circuit), how should the antenna be oriented relative to the direction of polarization of the wave? Explain.

6. **Test.** Use the signal generator and oscilloscope set up at the front of the room to test your predictions. Describe your observations and the results.

SPH4U: Polarization

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

When a light wave is received by our eyes, we cannot tell which direction the electric field vectors point in – but some creatures can! Certain materials react differently to electric or magnetic field vectors in different directions.

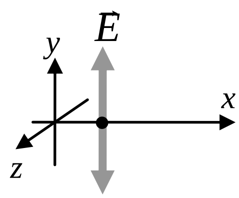
A: Through the Polarizing Glass

You will need a pair of polarizing filters. Be careful since some of them are glass!

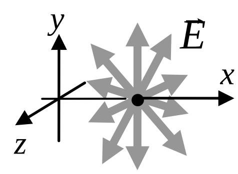
1. **Observe.** Look at the room lights through one of the polarizing filters. Describe how the filter affects what you see. Does rotating the filter have any effect?

2. **Observe.** Hold a second polarizing filter in front of the first, and look at the room lights again. Describe how the filter affects the light you see. How does rotating one of the filters with respect to the other affect what you see?

A light beam is *linearly polarized* when the electric field vectors throughout the beam point along a single axis. An *unpolarized* beam is made up of many rays of light, each of which has the electric field pointing in different, random directions.

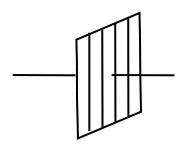


polarized beam

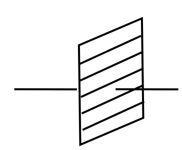


unpolarized beam

The EM wave that is transmitted from a polarizing filter (or *polarizer*) has its electric field vectors pointing *parallel* to the polarizer's *axis of polarization*. A polarizer absorbs the parts of an EM wave that have electric field vectors perpendicular to the filter's axis of polarization. The axis of polarization is a property of the material the filter is made from (usually long chains of plastic polymers). The axis is often marked by a line on the filter. A *polarization diagram* represents the direction of the E-field of the wave and the filter's axis.

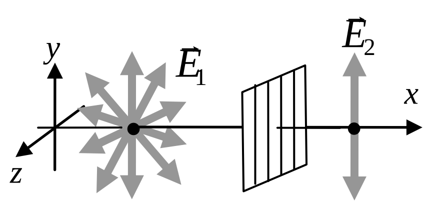


filter with vertical axis of polarization



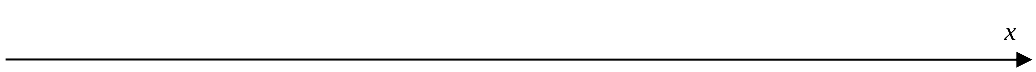
filter with horizontal axis of polarization

3. **Interpret**. Describe what is happening according to the polarization diagram to the right. Compare the brightness of the light at moments 1 and 2.



4. **Reason.** Do the room lights produce polarized light? Explain how you can tell from your observations.

5. **Represent**. Draw a polarization diagram for the situation of minimum intensity you found using the room lights and two filters. Describe the intensity of the light at each moment.

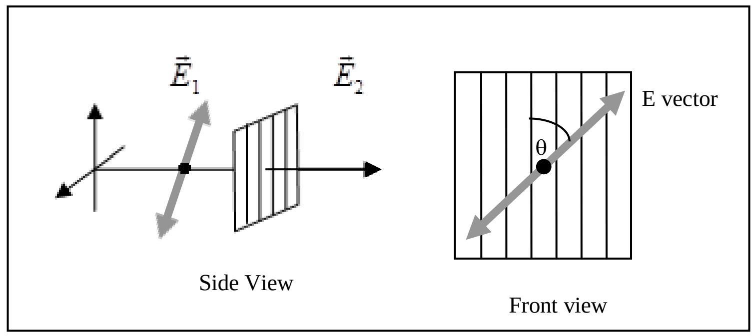


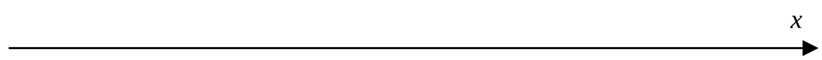
When two polarizers are oriented with respect to one another such that the light is at a minimum intensity, the polarizers are said to be *crossed* and all the light has been absorbed.

6. **Observe**. What are other sources of polarized light from around the classroom or amongst your belongings?

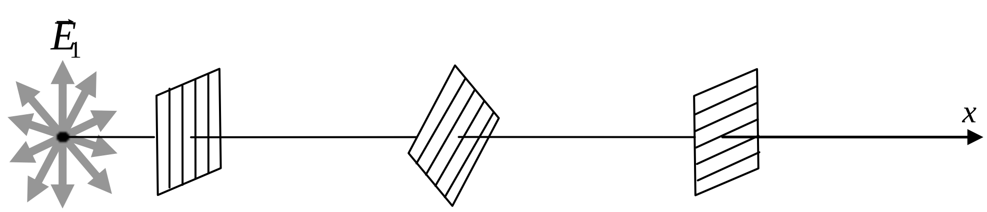
7. **Reason.** Suppose that you had a polarizer with its direction of polarization marked. How could you use this polarizer to determine the direction of polarization of another unmarked polarizer? Explain your reasoning.

8. **Reason.** A beam of polarized light is incident on a polarizer, as shown in the side view diagram. The direction of E-field of the light makes an angle θ with respect to the polarizer's direction of polarization (see front view diagram). The amplitude of the electric field of the incident light is E_1. Write an expression for the amplitude of the transmitted component of the electric field, E_2. Represent this in a polarization diagram.





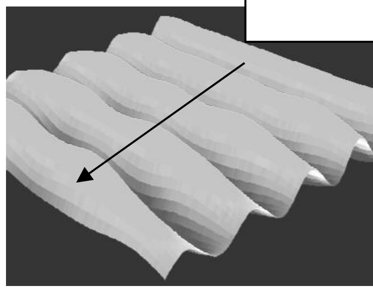
9. **Predict.** A beam of unpolarized light travels through a pair of crossed filters – no light is transmitted from the last filter**.** What will happen when a third filter, whose axis of polarization makes a 45^{o} angle with both filters, is placed between two crossed filters? Draw a polarization diagram. Describe the light intensity. Test your prediction – we will also try this as a class.

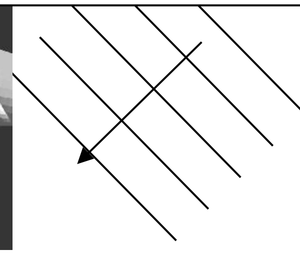


SPH4U: Modeling 2-D Waves	Recorder: __________________ Manager: __________________ Speaker: __________________ 0 1 2 3 4 5

A: Picturing Two-Dimensional Waves

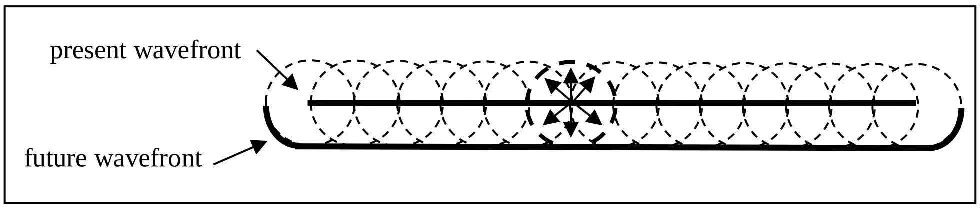
So far when we have described light waves, we have pictured waves travelling along a single line in space. But let's look at them another way now. We can draw pictures resembling the surface of water. Consider the illustration from the simulator www.falstad.com/ripple/. We can easily sketch this wave by drawing lines of *constant phase* such as crests or troughs. These represent the *wave fronts* and in this example, the wave fronts are fairly straight lines and are called *planar waves*.





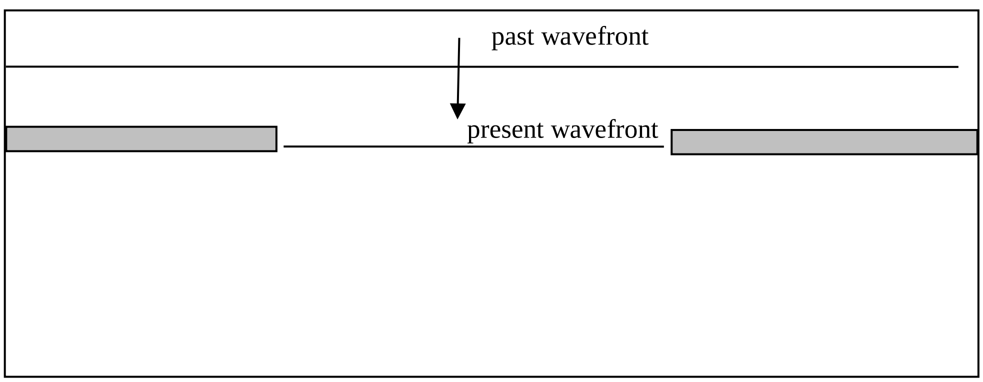
To understand how a 2-D wave works, we use an idea proposed by Christian Huygens in 1690. The fundamental wave motion is circular – imagine a pebble dropped in water and a circular wave rippling outwards. Huygens proposed that each point along a wave front can be considered to be a *point source of circular waves or wavelets*. When these circular waves travel outwards their wave fronts join together and form the future wave front of the present wave.

Use a small coin and draw a dot every radius along the present wavefront. Be sure to centre the coin at the two ends as well! Next, trace the outline of the coin when centred on each dot. Form the future wavefront by drawing a new surface tangent to the foreword edges of the wavelet circles. You can smooth this out, understanding that there are many more wavelets that we did not draw in between the ones we did.



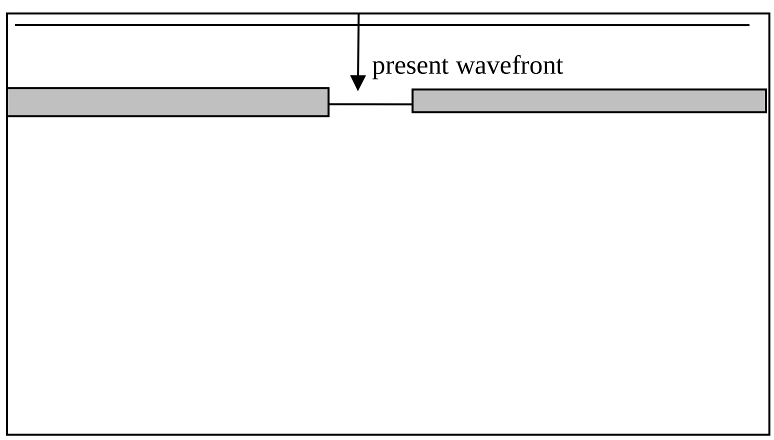
1. **Reason.** What does the radius of the coin represent about the wave?

2. **Represent.** We will use this technique to model what happens when a wave passes through the **wide** opening. Find the next three future wavefronts. Be sure to use points at the two ends of the previous wavefront!



3. **Represent.** Now try a really narrow opening. Construct the next three wave fronts. See if you can do this quickly now.

4. **Describe.** What happens to the shape of the original wavefront after it passes through an opening?



When a wave front changes shape as it travels through an opening or around a barrier we say it *diffracts*.

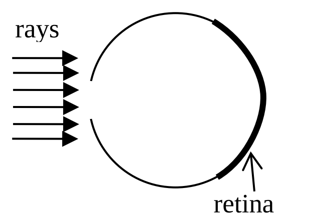
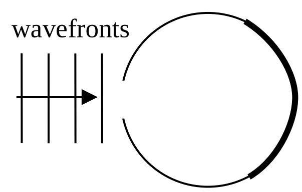
5. **Observe.** In which example above was the *diffraction* of the wave greatest (greatest change in shape)? Explain.

6. **Reason.** Compare the width of the opening with the wavelength. What condition is necessary for strong diffraction to occur?

The Diffraction Condition:

B: Eye Eye!

1. **Represent.** Back in gr. 10 you studied light using the model of rays. Based on the ray model, predict where light would strike the retina of your eye. Decide what region would be bright and what region would be dark. Do the same based on your understanding of wavefronts and diffraction.

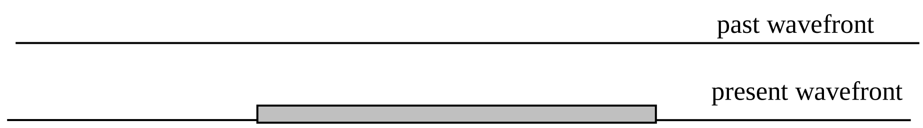
Geometrical Optics (light as rays)	Wave Optics (light as wavefronts)
	

2. **Test.** (as a class) Describe and sketch what happens to the light from a bulb at the front of the class as you gradually close your eyes until there is only a tiny, tiny opening.

3. **Test.** Keep your eyes mostly closed. Describe what happens when you tilt your head.

C: Special Effects

1. **Predict.** This is not related directly to the eye, but what happens when a wave meets an obstacle? In particular we want to study the region *behind* the obstacle. Find the next three wave fronts by making an educated guess (don't worry about the coin technique now).



2. **Test.** (as a class) Observe the results in the simulation. Describe what happens in the region behind the barrier.

SPH4U: Exam Preparation

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

Careful preparation for an exam helps you demonstrate the understanding you have gained through the hard work you have done during an entire course. Effective preparation depends on knowing your own strengths and weaknesses, using careful time management and employing the best studying strategies.

A: Know Thyself

Let's begin by thinking about what you currently do to prepare for a typical test.

1. **Reflect.** (*individually)* How much time in total do you typically spend perparing for a physics test? When do you do your preparations?

2. **Reflect**. (*individually)* When preparing for a test, what proportion of time do you spend on each of the following:

Summarization		Reviewing homework solutions	
Highlighting/ underlining		Solving problems for practice	
Rereading textbook or handbook sections		Other:	

3. **Reason.** (*as a group)* How effective have these strategies been for you? Rank the strategies listed above from most effective (1) to least effective (6). Record your ranking in front of each description above. Provide a rationale explaing why you think your top ranked and lowest ranked strategies are the best and worst for you.

B: Performance Anxiety

There are many occasions in life when we are faced with one shot at accomplishing a particular goal. Most people feel some level of stress or anxiety when performing under pressure.

1. **Reflect.** Describe a few situations that don't involve a test or exam in which you or other people you know have faced a high pressure situation.

2. **Reason.** High performance athletes and professional musicians are examples of people who routhinely perform under high pressure situations. How would such a person prepare in the days leading up to a crucial performance?

3. **Reason.** What strategies do you think a high-pressure performer uses during the performace itself to deal with stress and anxiety?

4. **Reason.** Describe some strategies you could realistically make use of for the upcoming exams.

C: Evaluating Study Strategies

Research has been done to measure the effectiveness of different strategies in student leaning and studying. Here are some results from: *Psychological Science in the Public Interest* 14(1) 4–58

Technique	Effectiveness	Rationale
Highlighting	Low	
Summarizing	Low	
Rereading	Low	
Self-explanation (explain aspects of the process to yourself while studying)	Medium	
Practice testing (practicing your understanding in a testing situation)	High	
Distributed Practice (spreading practice over a number of days)	High	

1. **Reason.** In the chart above, provide a rationale for the rating of each technique.

2. **Plan.** Which techniques would you like to include in your upcoming exam preparations? Explain how you might incorporate them.