SPH4U: Syllabus

Course Website: http://abelmoodle.abel.yorku.ca/moodle/course/view.php?id=387

This syllabus contains a list of all classes, topics and homework in the Gr. 12 physics course. You should always take notes from the listed readings. You are strongly encouraged to explore the simulations and videos listed for each lesson – they are optional but quite interesting! All the following links are also found on the course website – bookmark this for regular use.

There are many excellent online resources to help you understand physics.

- Early Haig Physics (www.physicseh.com): an excellent set of videos explain how to solve problems
- Khan Academy (http://www.khanacademy.org/#physics): short video lessons and worked-out problems
- Physics Classroom (http://www.physicsclassroom.com/Class/): good summaries of topics plus lots of multiple choice practise
- Active Physics (http://wps.aw.com/aw_knight_physics_1/17/4389/1123672.cw/index.html): many interactive tutorials with simulation – good for testing your understanding.

Warning! These excellent resources often use different notation than we do. Make sure you learn the notation as instructed in class!

Day	Topics	Homework
	Introduction	
1	Course Introduction, How to Answer a Question	Video: Top 10 Amazing Physics Videos
2	How Groups Work	Read: course handouts. Actually read the handouts.
3	The Art of Measurement	Handbook: *Numbers and Physics* Video: Scientific Notation
4	Numbers, Estimations and Fermi Questions	Handbook: *Fermi and Numbers* Lesson: Fermi Problems
	Kinematics	
1	Short quiz on Introduction How Noteworthy!	Gr. 11 Review Questions: 1-D Kinematics Gr. 11 Review Lessons: Kinematics Notes: pg. 18-23
2	Uniform Acceleration	Notes: pg. 24-7 Problems: pg. 27, #20-21, pg. 37, #9 Active Physics: Motion Diagrams Course website: *Graphing Kinematics Review Sheets*
3	Representations of Motion	Notes: pg. 11-3, 20-4, pg. 14 #15, 16 Handbook: *Converting Graphs of Motion* Active Physics: Graphs from Motion Active Physics: Motion from Graphs Video: Converting Between Graphs - Slopes Video: Converting Between Graphs - Areas
4	CGPS: Modeling Problem Solving	Problems: pg. 65 #18, 19 a, b Active Physics: Car Catches Truck Simulation: The Moving Man
5	CGPS	Notes: pg. 35-8, pg. 65 #21, 26 Active Physics: Balloonist Drops Lemonade Active Physics: Avoid the Collision
6	2-D Motion	Problems: pg. 24 #11, pg. 65 #27, pg. 67 #46 Simulation: Maze Game

7	Vector Components	Handbook: *Vectors and Components*, two pages Notes: pg. 756-7: *Vectors – Components of Vectors* Active Physics: Velocity Components Video: Components Video 1 Video: Components Video 2 Video: Components Video 3
8	Projectiles!	Notes: pg.41-45 Problems: pg. 46 #3, 5 Active Physics: Changing x-velocity Video: Velocity Vector Components Video: Crazy Motorcycle Jump
9	Projectile Problem Solving	Notes: pg. 46-48 Problems: pg.51 # 8, 9 Active Physics: Target Practice I Video: Projectile Problem Solving
10	Projectile Problem Solving *(continued)*	Problems: pg.51 #5, 7 Active Physics: Target Practice II Simulation: Projectile Motion
11	CGPS	Review: Projectiles (try #1-14, 35-39, 42-45, 51-53, 66, 71) See sample tests and resources online!
12	Test on kinematics and projectiles	NOTE: 2-D acceleration and relative motion are **not** part of this unit.

Forces

1	Representing Forces	Gr. 11 Review Lessons: Newton's Laws Gr. 11 Review Questions: Newton's Laws Hand Book: *Representing Forces*
2	Forces in 2-D	Notes: pg. 81-83 Problems: pg. 80 #1, 6a,b, pg. 83 #10, 13 Active Physics: Rocket Blasts Off Simulation: Forces in 1 Dimension Video: Simple Force Example
3	Understanding 2-D Forces	Notes: pg. 88-9 Problems: pg. 92 #6, 7 Active Physics: Sliding on an Incline Simulation: The Ramp: Forces and Motion Video: Forces with Angles 1 Video: Forces with Angles 2
4	CGPS	Problems: pg. 96 #8, 9
5	Newton's 3rd Law	Notes: pg. 93-94
6	Newton's 3rd Law (*continued)* Motion of Combined Objects	Problems: Pg. 94 #10, pg. 95-96 #3, 7 Lesson: Multiple Bodies
7	Weight and Acceleration	Problems: pg. 84 #16, pg. 93#9, pg. 150 #7, Notes: read ahead for next class. Video: Forces and Elevators
8	Frames of Reference	Notes: pg. 108-110 Problems: pg. 110 # 2, 3 Video: Frames of Reference
9	Tension and Pulleys	Problems: pg. 87 #9, pg. 92 #5 Active Physics: Atwood Machine Video: Atwood Machine
10	CGPS	Problems: pg. 95 #5, 10
11	Friction!	Notes: pg. 97-101 Problems: Pg. 101 #3, 5, 7 Active Physics: Push Crate Up Wall
12	Friction! *(continued)*	Problems: Pg. 118 # 16, 25(a) Active Physics: Skier Goes Down Simulation: Forces and Motion

		Video: Inclines with Friction Video: Pulley, Incline, Friction
13	Going in Circles	Simulation: Ladybug Motion 2D Video: Circular Motion Idea Video: Circular Motion Idea 2
14	Going in Circles *(continued)* Centripetal Acceleration	Notes: 122-126
15	Centripetal Acceleration (*continued)*	Problems: Pg. 126 #8, 10 Active Physics: Centripetal Acceleration Video: Conical Pendulum Video: Frames of Reference
16	Thinking About Circular Motion	Notes: pg. 130-133 Problems: Pg. 133 #3, Pg. 138 #7 Active Physics: Problem Solving Simulation: Ladybug Revolution Video: Tension in Vertical Circle
17	CGPS	Problems: pg. 161 #26, 27, pg. 171 #48 Active Physics: Car Circles Track
18	Universal Gravitation	Notes: pg. 139-142 Problems: Pg. 141 #3, pg. 143 #10, 12 Simulation: Lunar Lander Video: Universal Gravitation
19	Orbits	Problems: Pg. 147 #2, 6, table pg. 776 Active Physics: Satellites Orbit Lesson: Satellites Simulation: My Solar System Video: Gravity in Orbit Video: Why Doesn't the Moon Fall Down?
20	Orbits *(continued)*	Lesson: Orbital Calculations Video: Dark Matter
21	Test on Dynamics	Test Review: pg. 117 #7, 10, 24 (text answer wrong), 28, 29, pg. 168 #16, 19, 20, 23, 24, 26 Review: 2-D Forces Review: Gravity and Circular Motion (skip Kepler's Laws)

Energy and Momentum

1	"Oomph"	Notes: pg. 232-7, Problems: pg. 237 #6, 7, 10a Active Physics: Save an astronaut Video: Impulse Lesson: Impulse
2	Types of Collisions CGPS	Problems: pg. 243 #5, 7, 8 Active Physics: Elasticity Video: Intro to Momentum Lesson: Conservation of Momentum
3	Momentum and Isolated Systems Process of a Collision	Notes: pg. 246-8 Problems: pg. 248#6, pg. 251 #11-13 Active Physics: Momentum and Energy Lesson: Isolated Systems Video: Slow Motion Collision Video: Smart Car Collision
4	Car Crash! Conservation of Momentum in 2-D	Handbook: *2-D Momentum Problem Solving* Notes: pg. 256-8, pg. 257 #3, 4abd Video: 1968 Crash Test
5	2-D Collisions	Problem: pg. 257 #5 Active Physics: P and E Conservation Simulation: Collision Lab
6	2-D Collision Experiment	Problems: pg. 258#3, pg. 271 #32

7	Momentum Quiz, Working the Angles	Problems: pg. 181 #5, 7, pg. 183 #7, pg. 186 #4, 6, 10 Lesson: Work
8	Work and Kinetic Energy	Problems: pg. 191 #1, 4, pg. 197 #6, pg. 200 #13, pg. 201 #6 Active Physics: Work Simulation: The Ramp Video: Roller Coasters
9	Energy and Frames of Reference, Energy Transfers	Problems: pg. 201 #8, 10 Active Physics: Energy Bar Charts Simulation: Energy Skate Park
10	Rollercoasters and Energy	Handbook: *Amusement Park Physics* Active Physics: Skier Speed Lesson: Loop de Loop
11	The Ballistics Pendulum	Problem: pg. 270 #19, 20 Active Physics: Pendulum Bashes Box
12	Spring Force and Energy	Notes: pg. 203-206, Problems: pg. 206 #5 Notes: pg. 207-210, Problems: pg. 211 #10, 12 Video: Hooke's Law Video: Energy in Springs Video: Energy in Springs 2
13	Exploring Elastic Energy, Review	Review: pg. 307 #4, 5, 10, 18, 20, 26, 30, 37, 48 Active Physics: Inverse Bungee Simulation: Masses and Springs
14	CGPS	Problems: pg. 229 #37, 38 Review: Momentum Review: Work and Energy
15	Test	

Special Relativity

1	Velocity and Frames of Reference	Video: In Search of the Edge
2	The Light Clock Why Don't We Notice?	Notes: pg. 569-72 Problems: Pg. 573 #2, 3 Active Physics: Time Dilation Video: Special Relativity
3	Distance and Velocity Visualizing Relativity	Notes: pg. 573-575 Problems: Pg. 576 #5, 8 Active Physics: Length Contraction Video: Visualizing Relativity
4	Energy and Relativity	Problems: Pg. 583 #3, pg. 584 #5, 9 Video: Einstein Talks
5	Energy and Relativity	Check out: pg. 690-691 Problem: pg. 584 #8, pg. 591 #25 Video: Large Hadron Collider (LHC) Video: Proton Antiproton Collision
6	* Journey to Flatland	Check out: pg. 730-731 Video: Dr. Quantum Visits Flatland Video: Hypercube

Electric and Magnetic Fields

1	Relativity Quiz, A New Kind of Interaction	Notes: pg. 318 – 322 Simulation: Static Electricity
2	A New Kind of Interaction (*continued)*	Problems: pg. 324 #2, 3
3	The Strength of Electrostatic Interactions	Problems: pg. 331 #3, 5, 6 Active Physics: Coulomb's Law Video: Charge and Coulomb's Law
4	Analyzing Electrical Forces	Notes: pg. 332-334 Problems: Pg. 334 #8, 9 Active Physics: Combining Charges
5	Picturing Electric Forces	Simulation: Charges and Fields

		Lesson: Electric Force and Fields
6	The Electric Field Concept	Problems: pg. 343 #1, 2 Simulation: 3-D Electric Fields Lesson: Electric Field
7	The Superposition of Fields	Notes: pg. 342-3 Problems: pg. 343 #4, 6, 7 Active Physics: Electric Fields Active Physics: Field of Dipole Lesson: Calculating Electric Fields Lesson: Calculating Electric Fields 2 Simulation: Electric Field Hockey
8	Magnetic Fields	Notes: pg. 384-5 Problems: pg. 391 #4, 7 Active Physics: Field Around Wire Video: Magnetism Review
9	CGPS	Problems: pg. 358 #7 (questions), pg.379 #24, 27, 30, 35
10	Magnetic Forces on Charges	Problems: Pg. 396 #2-4, pg. 403 #4, 7 Active Physics: Magnetic Force Active Physics: Mass Spectrometer Simulation: 3-D Magnetic Fields Video: Force on Moving Charges 1 Video: Force on Moving Charges 2 Image: Hi-res Bubble Chamber
11	Electromagnetic Disturbances	Problems: pg. 534 #1, 2 Simulation: EM Waves Simulation: EM Waves 2
12	Understanding EM Waves	Simulation: Antenna
13	Light and Polarization	Problems: pg. 498 # 4 Active Physics: Polarization Lesson: Polarization Video: Polarizing Filters Video: Polarization and Internal Stress Video: LCD Screens Review: Electrostatic Forces and Fields
14	Test	Prepare next topic: 1-D waves Problems: pg. 379 #15, pg. 440 #7, 8, 11, 12

Light

1	Properties of 2-D Waves – diffraction, interference	Gr. 11 Review: Waves Notes: pg. 453-4 Problems: pg. 454 #2, 3 Simulation: 2-D Waves Video: Waves Review
2	Spatial interference: Part I	Notes: pg. 455-60, pg. 459 #3 Simulation: Sound Spatial Interference Simulation: Wave Interference Lesson: Two Point Interference Video: Path Length Difference
3	Spatial Interference: Part II	Problems: pg. 460 #4, 9 Simulation: Interference Lesson: Path Length Difference
4	Young’s Double-Slit	Notes: pg. 469-73, Problems: pg. 473 #1, 2 Lesson: Young’s Experiment Video: Double-Slit
5	CGPS	

SPH4U – Physics, Grade 12
University Preparation

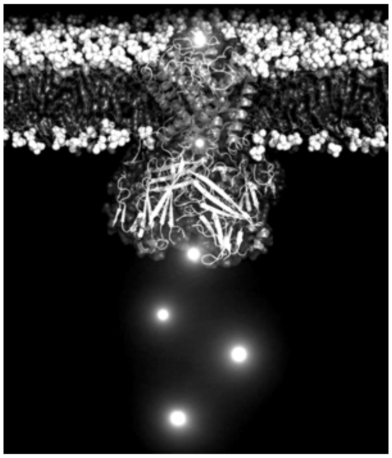
York Mills Collegiate Institute

Teacher: Mr. Meyer

Course Website: http://abelmoodle.abel.yorku.ca/moodle/course/view.php?id=387

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.

MIT: http://www.nytimes.com/2009/01/13/us/13physics.html
U of T: http://www.upscale.utoronto.ca/Practicals/Overview/Overview.html
Harvard: http://youtu.be/WwslBPj8GgI



Potassium Channel - It's All Physics

Text reading, Note-Taking and Homework
The majority of the class time will be spent doing activities and discussing physics with your colleagues. To accommodate this, you are required to do about 30 minutes of textbook readings almost every day and to take reliable notes from those readings. In class I will clarify and amplify the text in the minimum time possible and allow you to then explore the concepts through activity and discussion. In addition to the readings, you will have about 30 minutes of questions to solve. Daily textbook notes, homework problems and class investigations will be randomly checked for marks. The classroom will be open during the lunch hour for quiet study and extra help. *Plan enough time for one hour of physics homework each day.* Optional online lessons and resources are listed for each lesson.

Assessment and Evaluation
Due to the central role of group work in this course, the work you do in groups will account for an important portion of your mark. Daily group work will be randomly handed-in and marked. To help

ensure that individual students are pulling their weight in groups, there will be regular quizzes based directly on group work. A bonus will be given to groups whose members all score at least 75%. The content from your group work and home study will, of course, also appear on tests. There will be regular tests that survey each unit of our physics course. There is a final exam that covers the course's entire material and a major project that will be announced halfway through the course.

Mark Breakdown

The categories of *Knowledge and Understanding*, *Thinking*, *Communication*, and *Application* are a component of most of the evaluation tools 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 approximately as follows:

Knowledge and Understanding	28%	Tests ~ 7 % each
Thinking	14%	Random group work and regular quizzes ~ 1.5 % per group work check ~ 1.5 % per quiz
Communication	14%	Tests, Study Notes, and Note Checks ~ 1 % per note check ~ 1 % per study note ~ 3 % per test
Application	14%	Challenges (CGPS) and Project ~ 1 % per challenge ~ 7% for project

Attendance and Punctuality

Most of your work takes place in groups and by being either absent or late you handicap yourself and your group. Students are responsible for determining what was missed and making sure that they are caught up *before* the following class – exchange phone numbers and consult your group members as your first step. Any evaluations of group work a student is absent for will be awarded a zero unless a valid reason with appropriate documentation is presented when the student returns to school.

Missed Tests

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

- Let me 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 me immediately after setting foot in the school upon your return.
- Provide a doctor's note if the reason is illness.
- Do not discuss the test by any means with your colleagues.
- Be prepared to write the test immediately, at my discretion.

Failure to do any of these will result in a zero for that assessment.

Please Read This Document!

Please sign below signifying that you have read this course introduction.

____

Signature of parent, or student if 18 and over

____

Print name

SPH4U: How to Answer a Question?

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

Here is a question given to a grade 11 physics class after a kinematics activity where a car travels either directly or along a zigzag path from its starting point to a bowling pin.

Did today's activity help to differentiate between the terms distance and displacement?

Mark the student responses shown below using the following criteria:

a) Does it clearly answer the question asked? b) Is it complete?
c) Is the physics correct? d) Is it grammatically correct?

Use this marking scheme to determine the mark out of five:

0. Work that is completely missing.
1-2. Work that is seriously deficient, incomplete or lacking in fundamental understanding.
3. Work that shows basic comprehension but requires improvement.
4. Work which meets the expectations. The question is correctly and clearly answered.
5. Exceptional work which demonstrates a thorough understanding and examination of the topic. The question is thoroughly and thoughtfully answered.

Response 1 "Yes, since the distance the car travelled was not in a straight line it increased distance. When the car was travelling straight it represented displacement."

0 1 2 3 4 5 because ____

Response 2 "It did but since we weren't measuring every way the car went, (not straight) we didn't see the distance so that activity primarily focused on displacement. Displacement is the length from two points that an object travels and the change in the location of an object when it is moving between two points. Distance is how far the car went. I think today's activity was great. "

0 1 2 3 4 5 because ____

Response 3 "Today's activity helped me to differentiate between the terms distance and displacement. Distance (Δd) is the path length that the car traveled. Displacement ($\Delta\vec{d}$) is the length of a straight line segment directed from the spot where we dropped the car to the bowling pin." (Labelled diagram included)

0 1 2 3 4 5 because ____

Response 4 "Yes it does."

0 1 2 3 4 5 because ____

SPH4U: How Groups Work

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

Each group needs a whiteboard, marker and cloth. Assign each group member one role: **Manager, Recorder, or Speaker.** If there are four people in a group, two will act as the speaker. Working well in a group is a bit like acting in a play, we all have roles to perform!

Manager*: Ask the group members to read the following instructions for this activity.*

The majority of our work in Gr. 11 physics will take place in groups. Take a few moments to think about our experiences of working in groups. Think about your experiences in other courses and your experience so far in Gr. 11 physics. We will discuss these experiences, but please don't mention anyone's name!

Manager*: Ask the group to complete the next two questions individually, without any discussion. When you see that everyone has finished, have the group move on.*

Complete the following two questions individually.

1. In your experience, what are some of the enjoyable characteristics of working in groups?

2. In your experience, what are some of the less-enjoyable characteristics of working in groups?

Work together now. On your whiteboard compile a list of the group's responses to each question.

Manager*: Organize the discussion and ask for ideas from each group member.*
Recorder*: Neatly* ***summarize*** *the ideas on the whiteboard, write large enough so other groups could read it if you were to hold it up.*
Speaker*: Be prepared to speak to the class about your points when your group is called upon – if any points are unclear, ask your group questions.*

Continue the following questions as a group.

Manager: *Read out the next question and ask the group for their ideas. Kindly ask everyone for their input.*
Recorder: M*ake sure what you write down on your own sheet accurately represents the group's ideas – your teacher will be checking your copy. Ask the other members for clarification if you're not sure you have it right*.
Speaker: *Be prepared to speak on behalf of the group. If any ideas are not clear, ask the others for an explanation or ask specific questions*. *Make sure the group explanations would receive a mark of "5" – are they thorough and complete?*

We have all experienced difficulties working in groups. Sometimes, the challenge comes from within – for whatever reason you, as an individual, are unable to contribute effectively to the group. Other times, another group member may make the proper functioning of the group difficult.

3. Think about the reasons why a group might *not* function at its best. Make a list of the reasons in the chart below – be specific. However, do **not** mention the names of any individuals. This is **not** a critique of your current group or any others you have been in.

Reason Groups Might Not Work Well	Actions
1.	
2.	
3.	
4.	

4. Describe what specific actions could be taken to help the group work better in each case you listed above. Indicate which group member (R, M, S) would be best to carry out the action, or if it is an action for everyone (E).

Check your results with your teacher.

Manager: *When the group decides it had finished question 4*, c*all the teacher over. Keep an eye on the clock since we want to complete the whole activity in this period.*
Recorder: *The teacher will ask you to write up one example on the whiteboard for a class discussion. Have the others check this.*
Speaker: *Be prepared to speak on behalf of your group when called upon. Make sure the action is clear and precise.*

Manager: *Lead the group through the next question.*

5. Begin by working individually on the next question. In the chart below, list the responsibilities of your role in the group. When everyone is complete, share and discuss the results. Finally, complete the rest of the chart.

Manager	Recorder	Speaker

SPH4U: Group Work

The Idea

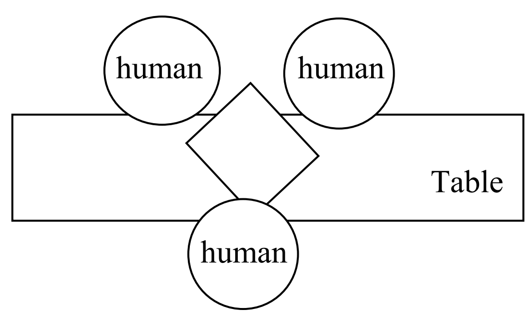
Group work is the main teaching format of the Gr. 12 physics course. Think of your group as your learning team - the people who will help you learn physics. Group membership will change every 10 to 20 classes or major unit, depending on the flow of the units in the course and will always have a heterogeneous composition of students (all ability levels) of my design. Every student is expected to take-up a specific role within the group and to carry out the responsibilities listed below. Members of every group will evaluate one another on their performance in their respective roles. Roles within a group must change for each new task or activity.

Group Roles

Actions	What it sounds like
Manager • Make sure everyone has read the initial instructions before starting. • Direct the sequence of steps. • Keep your group "on-track." • Make sure everyone in your group participates. • Watch the time spent on each step.	*"Has everyone had a chance to read this before we continue?"* *"Let's come back to this later if we have time."* *"We need to move on to the next step."* *"Ralph, what do you think about this idea?"*
Recorder • Act as a scribe for your group. • Check for understanding of all members. • Make sure all members of your group agree on plans and actions. • Make sure names are on group products.	*"Do we all understand this diagram?"* *"Explain why you think that."* *"Are we in agreement on this?"*
Speaker • Speak on behalf of your group when called upon in class discussions • Help your group avoid coming to agreement too quickly. • Make sure all possibilities are explored. • Suggest alternative ideas. • Energize your group when motivation is low by suggesting a new idea	*"What other possibilities are there?"* *"Let's try to look at this another way."* *"I'm not sure we're on the right track."*

Seating

When working in groups, please sit at the tables as illustrated to the right. This helps ensure that all members are able to interact easily with one another. When sitting three in one row, usually one person at the side is left out. I will constantly harass you to do this.



Whiteboards

One of the best ways to share work and ideas is using a whiteboard and your group's common workspace. This is much easier than all huddling around one sheet of paper. Please use these regularly!

SPH4U: Numbers and Physics

Physicists think about numbers in different ways compared with most people and even mathematicians. For example, if you think about the idea of the size of numbers (quantity), there are really three kinds: BIG numbers (greater than one), unity (equal to one), and small numbers (less than one). It is important to know how these numbers behave under mathematical operations. **All your work on this page should be done without a calculator!**

1. Estimate whether the result of each expression is BIG, small, or close to one.

a) 1 / BIG	b) 1 × BIG	c) 1 / small	d) 1 × small
e) BIG + small	f) BIG – small	g) BIG × small	h) BIG / small
i) small / BIG	j) BIG / (small + BIG)		k) BIG × BIG

Physicists are often interested in the general patterns illustrated by numbers rather than their specific values.

Students and even some teachers rely too much on calculators to do their thinking about numbers. As a physicist you should feel comfortable thinking about and using numbers in scientific notation without a calculator in sight!

2. Describe an easy way to compute: $6\times10^6 + 5\times10^6$ without a calculator.

3. Compute these expressions. No calculators!
   a) $6.5\times10^5 \quad + \quad 3\times10^5 \quad =$
   b) $6.4\times10^{12} \quad + \quad 2.9\times10^{12} \quad =$

4. Describe an easy way to compute: $(3\times10^2)(6\times10^6)$ without a calculator.

5. Compute these expressions.
   a) $3\times10^4 \quad \times \quad 2\times10^4 \quad =$
   b) $6\times10^2 \quad \times \quad 8\times10^2 \quad =$

   a) $4.9\times10^{340} \quad \div \quad 7\times10^{90} =$

6. Describe how to use **estimations** and scientific notation to **easily** compute: 2 168 222 × 4 937 without a calculator.

7. Estimate the results of these expressions.
   a) 1 168 222 × 6 900 000 =
   b) 0.0529 × 8.0036 =

SPH4U: The Art of Measurement

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

Measurements are 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 is mostly guess work and hunches.

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 and Reason.** Three students use the meter stick to measure the height of a desk and each reports their results: 95 cm, 94.8 cm, 95.03 cm respectively. Considering the intervals marked on the meter stick, which result illustrates the best use of this measuring device? Explain.

2. **Reason.** How accurate a measurement can you make with a meter stick (i.e. to the nearest…)? This represents the reading error of the metre stick.

The term *significant figures* describes which digits in a number or measurement are physically meaningful or reliable.

3. **Reason.** How many significant figures did the measurement you chose in question 2 contain?

4. **Reason.** Your teacher carefully measures the height of a chair and reported the result: 94.2 cm ± 0.1 cm, which shows the estimated reading error in that value. Marie brings her metre stick, measures the height of the same chair and reports a result of 94.3 cm ± 0.1 cm. Albert also tries and gets a reports a value of 94.5 ± 0.1 cm. Do these results "agree" with the teacher's result? Explain (Hint: what do you think "agree" means when we compare measurements?)

5. **Observe.** Measure the height of your desk, write it with an appropriate number of significant figures and include your estimated reading error.

B: The Stopwatch

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

A student drops a pencil from a 1.00 m height. Another student times the fall. The stopwatch readout looks like this after the timing: 0:00.45

1. **Observe.** Write this reading as a number in normal, decimal notation with units of seconds (s).

2. **Reason.** What is the accuracy of the stopwatch according to its display (i.e. to the nearest …)? This is the stop watch reading error.

3. **Observe.** Perform the measurement five times, record the times below and calculate an average time.

					Avg:

General Guideline for Significant Figures: When performing calculations, write the intermediate results with one extra significant figure and the final answer with no more significant figures than the least accurate piece of data. This is a handy rule of thumb. In university you will learn a mathematical system for determining the error in your calculated results which will replace this very simplistic guideline.

4. **Reason.** Examine the individual measurements in your chart above. You probably notice quite a bit of variation in them. Do they differ from one another by more than the reading error? Suggest reasons why.

General Guideline for Errors: There are often many sources of error in an experiment which will have an effect on the accuracy of a measurement. Try to simply estimate how much error there is. (When you study data analysis you will learn a much more reliable way of doing this called the *standard deviation* – we do not use this in gr. 12 physics.) Whenever you record a measurement, include the error, or note the error for a set of similar measurements. When measured quantities are used in calculations, the best we can do in grade 12 is to estimate a reasonable final error based on significant figures. In university you will learn more reliable techniques.

5. **Reason.** Based on your answer to question B#4, how many digits in your average time value should you consider significant? Rewrite your average and include a new estimated value for the error based on your observations in question B#4.

6. **Observe and Predict.** Choose an interesting place where you can carefully drop your pencil from. Measure the starting height of the pencil and predict the time it will take for the pencil to drop. (No stopwatches yet! Use the equation: $\Delta d = v_1\Delta t + \frac{1}{2}a\Delta t^2$ and $a = 9.8\ \text{m/s}^2$) Estimate an error based on the height measurement.

7. **Observe and Evaluate.** Describe a procedure to measure the time taken for the pencil to drop. Find the value including an estimated error (no fudging – this is science!) Does your measurement agree with the prediction?

SPH4U: Fermi Questions

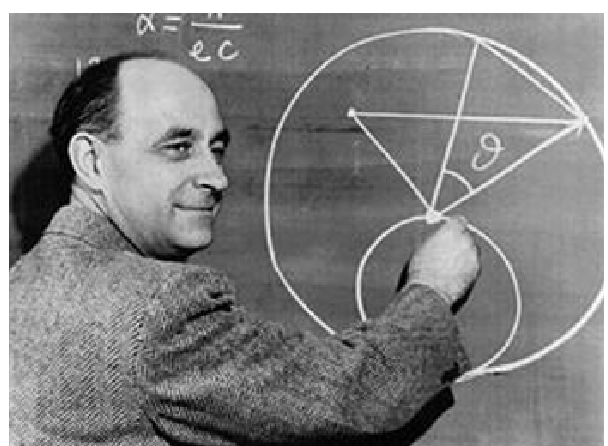
Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

Use point-form explanations and simple calculations to justify your estimated answer for each problem. Important: **whenever** you simply state a number, unless it is a well-known fact, you must justify it with a simple statement. State the final answer in scientific notation with only one significant figure.

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

2. How many cups of water are needed to fill a standard bathtub?

3. How many breaths would Julius Caesar have taken if he were still living today?



Fermi estimating the size of his bald spot.

SPH4U: Fermi and Numbers!

Write a complete solution (don't skimp on the steps) for the Fermi problem: How many postage stamps would it take to completely cover a soccer field?

How are your number skills? Getting better? Try some more!

1. Adding numbers using scientific notation
   a) $6.0 \times 10^{7} + 5.0 \times 10^{7} =$
   b) $1.9 \times 10^{3} + 3.4 \times 10^{3} =$
   c) $7.6 \times 10^{-2} + 1.8 \times 10^{-2} =$
   d) $4.6 \times 10^{4} + 6 \times 10^{3} =$
   e) $8.7 \times 10^{2} + 3.53 \times 10^{3} =$
   f) $1.0 \times 10^{-4} + 9.1 \times 10^{-4} =$
   g) $2.9 \times 10^{12} + 5.1 \times 10^{12} =$
   h) $6.1 \times 10^{-3} + 7 \times 10^{-4} =$

2. Subtracting numbers in scientific notation
   a) $4 \times 10^{3} – 8 \times 10^{3} =$
   b) $1 \times 10^{5} – 4 \times 10^{5} =$
   c) $2.0 \times 10^{11} – 1.4 \times 10^{11} =$
   d) $9.0 \times 10^{6} – 8.0 \times 10^{6} =$
   e) $9 \times 10^{-4} - 6 \times 10^{-4} =$
   f) $5.8 \times 10^{9} – 1.2 \times 10^{9} =$
   g) $3.5 \times 10^{6} – 2 \times 10^{5} =$
   h) $1.7 \times 10^{3} – 1.6 \times 10^{3} =$

3. Multiplying numbers in scientific notation
   a) $4 \times 10^{7} * 2.0 \times 10^{3} =$
   b) $1.0 \times 10^{3} * 6.4 \times 10^{-1} =$
   c) $6 \times 10^{-2} * 7 \times 10^{-4} =$
   d) $1.2 \times 10^{4} * 4 \times 10^{3} =$
   e) $7 \times 10^{-5} * 3 \times 10^{-7} =$
   f) $3.0 \times 10^{-12} * 3.0 \times 10^{12} =$
   g) $4 \times 10^{12} * 8 \times 10^{18} =$
   h) $1.5 \times 10^{-3} * 3 \times 10^{-2} =$

4. Test yourself! Do this in less than 2 minutes!
   a) $7.6 \times 10^{8} – 1.4 \times 10^{8} =$
   b) $7.0 \times 10^{-9} * 4.0 \times 10^{7} =$
   c) $6.6 \times 10^{13} \div 6.0 \times 10^{5} =$
   d) $1.2 \times 10^{362} + 8.4 \times 10^{362} =$
   e) $8.0 \times 10^{6} * 1.1 \times 10^{-4} =$
   f) $9 \times 10^{-4} - 2 \times 10^{-4} =$
   g) $3.9 \times 10^{-3} \div 1.3 \times 10^{-8} =$
   h) $2.9 \times 10^{-5} + 3.1 \times 10^{-5} =$
   i) $7.6 \times 10^{8} – 1.4 \times 10^{8} =$
   j) $7.0 \times 10^{-9} * 4.0 \times 10^{7} =$
   k) $6.6 \times 10^{13} \div 6.0 \times 10^{5} =$
   l) $1.2 \times 10^{362} + 8.4 \times 10^{362} =$
   m) $8.0 \times 10^{6} * 1.1 \times 10^{-4} =$
   n) $9 \times 10^{-4} - 2 \times 10^{-4} =$
   o) $3.9 \times 10^{-3} \div 1.3 \times 10^{-8} =$
   p) $2.9 \times 10^{-5} + 3.1 \times 10^{-5} =$

SPH4U: How Noteworthy!

An important part of our course is the taking of good quality notes from your textbook. This is meant to help you solidify what you have learned during that day's lesson. Your notes will be randomly checked for quality and completion, and are expected to be completed by the following class. You syllabus lists all the notes you are expected to take. For example, today your syllabus says:

Kinematics

1	Short quiz on Introduction Taking Notes	Gr. 11 Review Questions: 1-D Kinematics Gr. 11 Review Lessons: Kinematics Notes: pg. 18-23

Physics Course Notes

A: Read

Read the entire section first – beginning to end. Don't skip the boxes in the margins or the sample problems! Always ask the question, "OK, but why?" Read the pages listed above. Now.

B: Key Ideas

Identify what you think the key physics ideas are. These are usually **concepts**, such as "force and mass affect an object's acceleration" or "in the absence of air resistance, all objects fall at the same rate of acceleration. In point form, briefly note below what key ideas you came across in your reading. Whenever possible, **write in your own words**.

C: Definitions

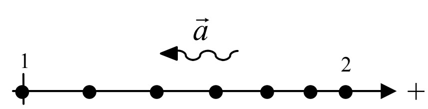
Record the definitions of important physics ideas or quantities. This should be both verbal and mathematical whenever possible.

D: Examples

Our goal when taking notes is to avoid direct copying, which requires very little thinking. When your notes are carefully organized, it is easy to refer back to your textbook for any lengthy passages that you might be tempted to copy out. So don't! Instead, explain the **logical process** of the solutions

For example, consider Sample problem 2, pg. 19. Your summary might go like this:

We know the initial velocity ($\vec{v}_1$), average acceleration ($\vec{a}$) of the motorcycle and the time while it brakes (Δt). Since the motorcycle is slowing down, we can use the definition of acceleration $\left(\vec{a}_{av} = \dfrac{\vec{v}_2 - \vec{v}_1}{\Delta t}\right)$, rearrange it, and solve for the final velocity ($\vec{v}_2$).



The description is complete if a typical student would be able to **understand** and solve the problem by following your instructions, given the actual values. A more complicated problem may involve a few more statements, but would read in a similar way. Include a **motion diagram** or a **force diagram** whenever appropriate.

E: Format

A consistent and clear format will help you organize your notes. Please follow this guide:

Sample Notes

Unit: Kinematics Topic: Acceleration in One Dimension (pg. 18-23) Idea: ⎫ Definition: ⎬ Repeat as necessary Examples: ⎭ Homework problems:

F: Homework Problems

It is often helpful to include your homework problems with the notes themselves. To earn full marks, homework must be shown using the GRASP procedure (see tomorrow's investigation for details.)

G: Passing Notes!

On a separate sheet of note paper, use the format above to take notes from pages 18-23. This may take about 20 minutes for you to do. Your goal is a note that is neat, complete and concise so that it will be a useful study aid. When you have completed you notes, pass your note and this paper to your neighbour and they will mark it! Use our regular marking scale where 5 = exceptional work, 4 = good, and 3 = basically OK.

H: Evaluating Notes

	Neighbour 1	
Follows format, organized and neat	5 4 3 2 1 0	Messy, disorganized, format missing
Key ideas well explained with appropriate definitions	5 4 3 2 1 0	Key ideas missed or poorly explained, definitions lacking
Examples carefully summarized with clear instructions, diagrams	5 4 3 2 1 0	Examples poorly explained and missing key steps
Overall, a clear note that would be valuable to study from	5 4 3 2 1 0	Very unhelpful - four months from now you will have no idea what this note is about

Suggestions, if any, to improve: ____

	Neighbour 2	
Follows format, organized and neat	5 4 3 2 1 0	Messy, disorganized, format missing
Key ideas well explained with appropriate definitions	5 4 3 2 1 0	Key ideas missed or poorly explained, definitions lacking
Examples carefully summarized with clear instructions, diagram	5 4 3 2 1 0	Examples poorly explained and missing key steps
Overall, a clear note that would be valuable to study from	5 4 3 2 1 0	Very unhelpful - four months from now you will have no idea what this note is about

Suggestions, if any, to improve: ____

SPH4U: Uniform Acceleration

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

A: Uniform Acceleration

1. **Reason.** Describe how you can determine whether something is moving with uniform acceleration using a stopwatch and a police radar gun.

2. **Explain.** Use the words "cause" and "effect" to help explain the relationship between acceleration and force.

3. **Evaluate.** Consider the following sequence of events: (1) A ball is at rest on an incline against your hand and you begin to exert a steady force on the ball up the incline. (2) The ball leaves contact with your hand as it continues rolls up the incline. (3) It reaches its highest point. (4) The ball is rolling back down the incline.
   (a) Albert explains, "The ball is accelerating uniformly from moment (1) until moment (3)." Do you agree? Explain.

   (b) Marie says, "The acceleration of the ball changes at moment (3). This makes sense because of the forces and the changing direction of the ball." Do you agree? Explain.

4. **Explain.** Use the word "forces" to help explain to your friend (who hasn't taken physics) a simple way to decide whether an object's acceleration has changed.

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, $\Delta\vec{d}$, $\vec{v}_1$, $\vec{v}_2$, $\vec{a}$, and Δt , for that time interval are related by the BIG 5 equations.

Note that $\vec{v}_1$ and $\vec{v}_2$ are the instantaneous velocities at the moment in time when two events occur. We will always use numerical subscripts to label different moments in time. Make sure the object is accelerating uniformly during the entire time interval between the two events you choose – otherwise you need to choose new events!

	$\Delta\vec{d}$	$\vec{v}_1$	$\vec{v}_2$	$\vec{a}$	Δt
$\vec{v}_2 = \vec{v}_1 + \vec{a}\Delta t$					
$\Delta\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$					
$\Delta\vec{d} = \frac{1}{2}(\vec{v}_1 + \vec{v}_2)\Delta t$					
$\Delta\vec{d} = \vec{v}_2\Delta t - \frac{1}{2}\vec{a}(\Delta t)^2$					
$\vec{v}_2^2 = \vec{v}_1^2 + 2\vec{a}\cdot\Delta\vec{d}$					

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.

2. **Apply.** Describe how you can use the chart to help choose the best equation to solve a problem with. For example, $v_1 = 5$ m/s, $a = 2.6$ m/s^2, $\Delta d = 12.7$ m, $\Delta t = ?$

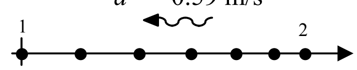
3. **Reason.** The BIG 5 equations, how many quantities (pieces of data) do you need to know in order to be able to solve for any unknown kinematic quantity?

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

C: How to Write a Solution

Solution writing is like writing an essay: not only must you have the right ideas, but they must be convincingly presented using proper grammar and form.

The **BIG 5** are vector equations. This means they take into account the direction of the kinematic quantities. A simple way to handle direction information is to use a sign convention and write down the BIG 5 as scalar equations.

Full vector notation	Scalar notation with a sign-convention
$\Delta\vec{d}$ = 53 m [E] $\vec{v}_1$ = 12.4 m/s[E] $\vec{a}$ = 0.59 m/s^2 [W] Δt = ? $\Delta\vec{d} = \vec{v}_1\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$	a = - 0.59 m/s^2  v_1 = 12.4 m/s Δd = 53 m Δt = ? $\Delta d = v_1\Delta t + ½a(\Delta t)^2$

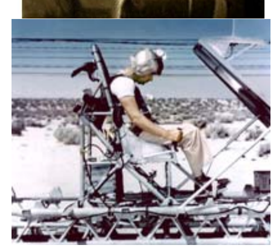
Each set up shown to the right is correct; the scalar version is often simpler and quicker to write down. **This will be our preferred method**.

A common method for writing solutions is the GRASP technique. This should be used for all your formal work and your homework questions. The five steps are:

GIVENS	Draw a **physics diagram** (motion diagram, force diagram or both!), identify any **important events** and attach all the given information along with symbols. Indicate the coordinate system and sign convention. Perform any conversions.
REQUIRED	Indicate on the diagram the quantity that you are looking for.
APPROACH	Write down the key equations you will use – no substitutions yet!
SOLUTION	Perform the mechanics of finding the answer – **do the algebra first**. Only then substitute numbers with units. Compute a final answer.
PARAPHRASE	State your result in a sentence that answers the question.

Here is a sample problem to complete with the GRASP solution method. Work out your solution below and also write it on a large whiteboard which will be used to share with the class.

Solve. 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?



SPH4U: Introduction to Cooperative Group Problem Solving

The purpose of this problem solving strategy is to help you learn the more sophisticated techniques that experts use. The focus here is thinking about the problem and planning **before** starting the math work. It is **very** important that you complete the set-up (parts A, B and C) before you do the math work (parts D and E). The manager has the critical role of ensuring this. The solution sheet will help to keep your group on track – be sure to fill it out as you go.

Best way to work: As a group, start each step by jotting down ideas on the whiteboard. When they are agreed upon and understood, the recorder writes out the good version on the solution sheet. The group should agree on and understand everything that is written on the solution sheet.

Set-up

A. The Picture

- Draw a clear diagram showing what's happening
- Attach the important information to the diagram using simple phrases
- Make any important measurements
- Attach the unknowns to the diagram if possible
- Indicate the coordinate system and sign convention

If this step is complete, you should never have to refer to the problem statement again.

B. The Question

- Create a specific physics question that will give the answer to the problem.
- Indicate which quantities will allow you to answer the question.

C. The Plan

- Summarize the physics that takes place
- Mentioning any important assumptions
- Outline the key steps in solving the problem
- List any useful "textbook" equations (i.e. found in bold / in a box in a text) and any other relationships you will use

Have you carefully completed all the previous steps? If not, go back! Note that you should not have done any real math work yet.

Execution

D. The Work

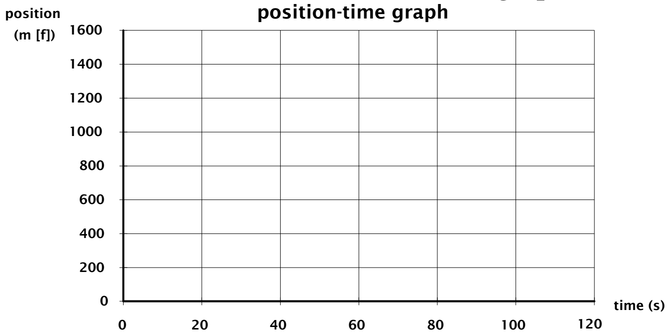
- Create the specific equations you will use –write them down with a simple statement explaining what you are doing. You should only use symbols that appear in Part A.
- Perform the algebraic manipulations first, whenever practical.
- Verify the units of the final derived expressions (the ones you will substitute numbers into).
- No number crunching yet!

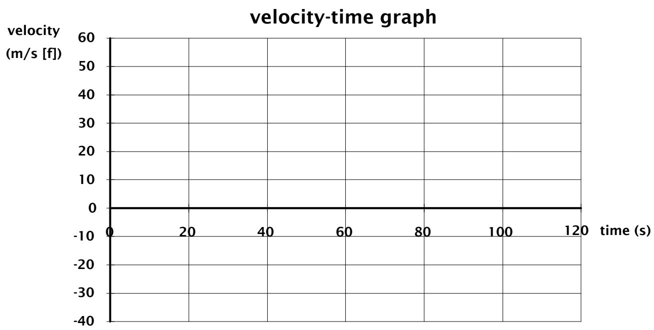
E. The Results

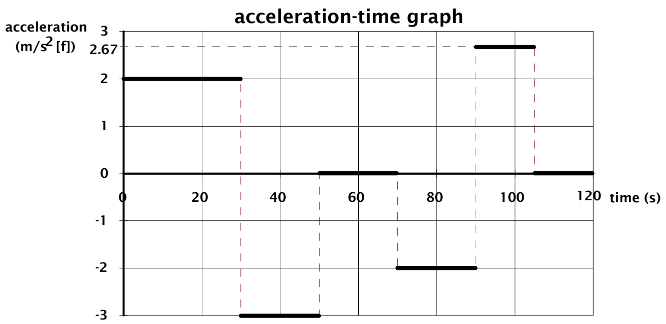
- Substitute numbers into your manipulated equations and calculate a result.
- State the final answer in response to the question you created.
- Write brief statements explaining why the answer seems reasonable in size, direction and units.

SPH4U: Converting Kinematics Graphs

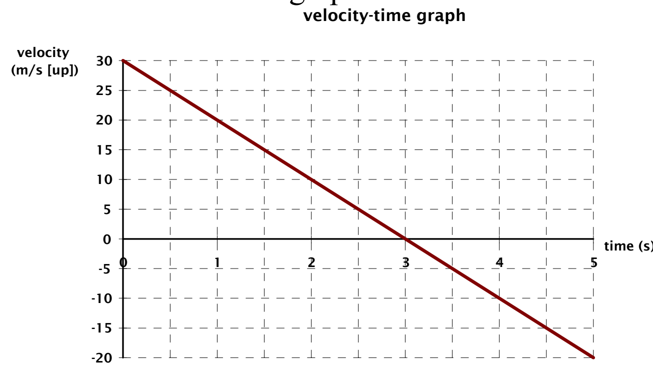
1. Given that the initial position and velocity are zero, complete the following velocity-time and position-time graphs from the data contained in the acceleration-time graph:



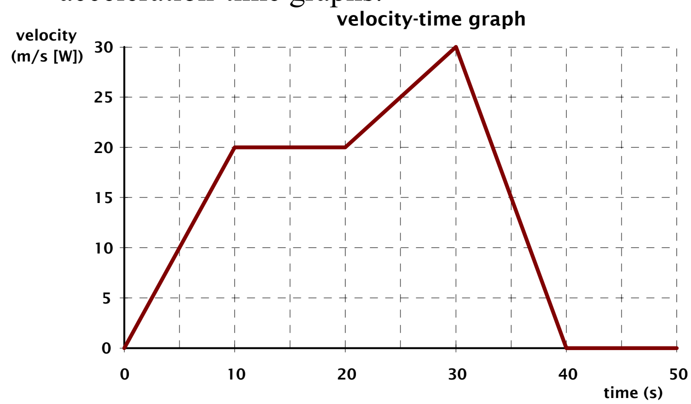




3. Given that the initial position is zero, and the following velocity-time graph, plot the corresponding position-time and acceleration-time graphs:



4. Given that the initial position is zero, and the following velocity-time graph, plot the corresponding position-time and acceleration-time graphs:

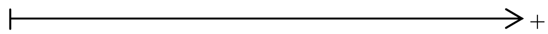
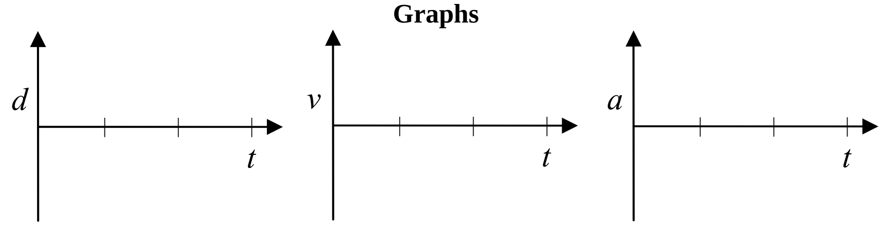


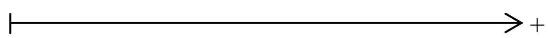
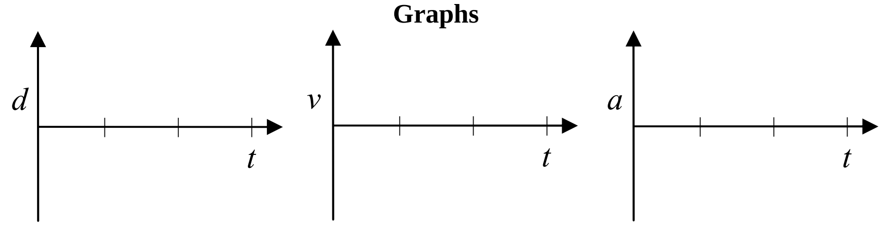
SPH4U: Representations of Motion

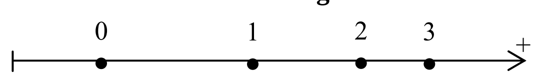
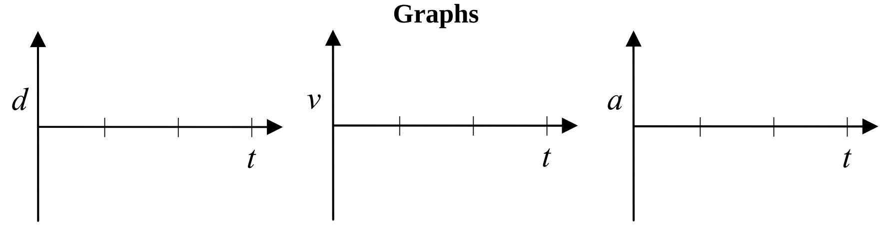
Recorder:	____________________
Manager:	____________________
Speaker:	____________________
	0 1 2 3 4 5

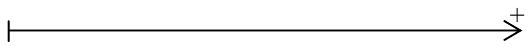
A cart travels along a track under a variety of situations. Use the information provided to complete all the other representations of motion. A coordinate system with the positive direction to the right is used and the origin is at the left end of the track. For the "Vectors" box, draw a vector representing the direction the acceleration and draw a velocity vector at four equally spaced moments in time. The sample equation is one possible equation that represents the desired motion. Begin by looking through all the examples shown on these two pages.

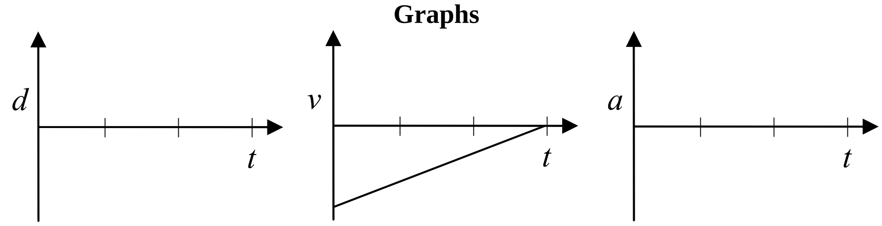
<table>
<tr><td rowspan="2">1</td><td rowspan="2">Description of Motion

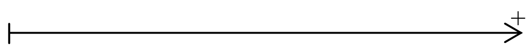
The cart starts at rest from the origin, moves in the positive direction and speeds up.</td><td>Motion Diagram
</td><td rowspan="2">Vectors
a:
v_0:
v_1:
v_2:
v_3:</td></tr>
<tr><td>Sample Equation
$d = (0\text{ m}) + (0\text{ m/s})\Delta t + \frac{1}{2}(1.2\text{ m/s}^2)\Delta t^2$</td></tr>
<tr><td colspan="2">Real-Life Situation</td><td colspan="2">Graphs
</td></tr>
</table>

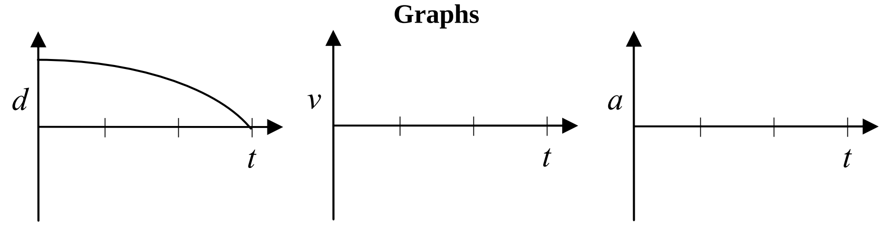
<table>
<tr><td rowspan="2">2</td><td rowspan="2">Description of Motion</td><td>Motion Diagram
</td><td rowspan="2">Vectors
a:
v_0:
v_1:
v_2:
v_3:</td></tr>
<tr><td>Sample Equation
$d = (17\text{ m}) + (5\text{ m/s})\Delta t + \frac{1}{2}(0\text{ m/s}^2)\Delta t^2$</td></tr>
<tr><td colspan="2">Real-Life Situation</td><td colspan="2">Graphs
</td></tr>
</table>

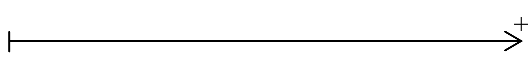
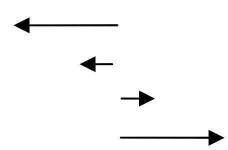
<table>
<tr><td rowspan="2">3</td><td rowspan="2">Description of Motion</td><td>Motion Diagram
</td><td rowspan="2">Vectors
a:
v_0:
v_1:
v_2:
v_3:</td></tr>
<tr><td>Sample Equation</td></tr>
<tr><td colspan="2">Real-Life Situation
A car passes straight through a traffic light and only begins slowing down in the intersection.</td><td colspan="2">Graphs
</td></tr>
</table>

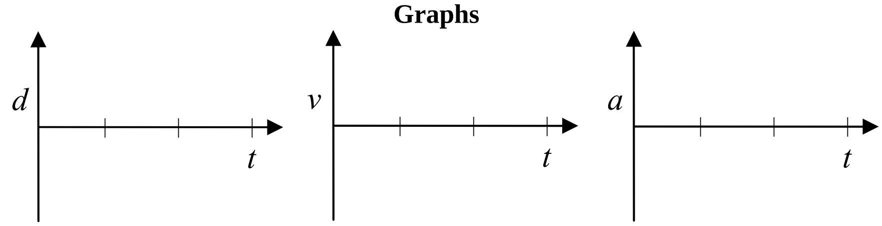
4	Description of Motion	Motion Diagram	Vectors
			a: v_0: v_1: v_2: v_3:
		Sample Equation	

Real-Life Situation	Graphs
	

5	Description of Motion	Motion Diagram	Vectors
			a: v_0: v_1: v_2: v_3:
		Sample Equation	

Real-Life Situation	Graphs
	

6	Description of Motion	Motion Diagram	Vectors
			a: v_0: v_1: v_2: v_3: 
		Sample Equation	

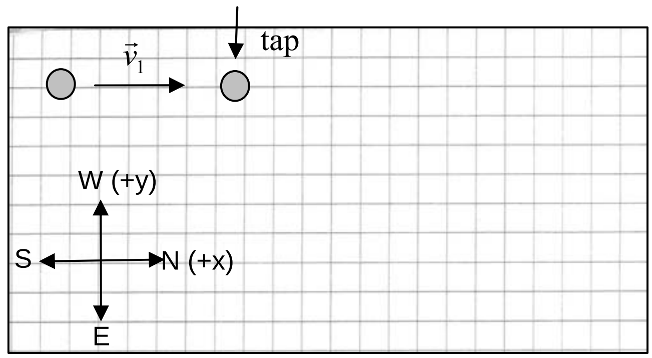
Real-Life Situation	Graphs
	

SPH4U: 2-D Motion

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

A: One Tap

Consider a hover puck moving with an constant initial velocity, $\vec{v}_1$, as shown below. It is given one short 'tap' in a direction that is perpendicular to its motion. **Note**: All 'taps' in these scenarios are always directed east! When asked to explain, try to use the word 'force' where appropriate.



1. **Predict.** How will the 'tap' affect the puck's velocity in the *y*-direction? Explain.

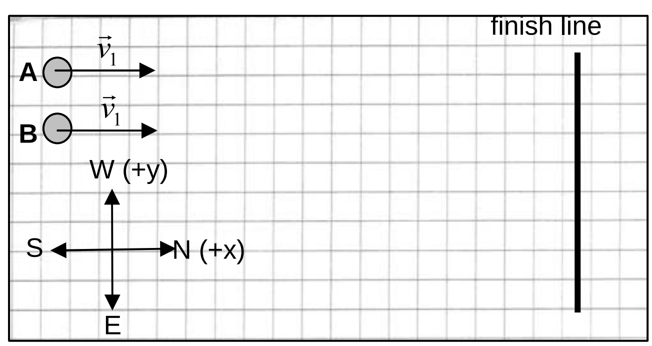
2. **Predict.** How will the tap affect the velocity of the puck in the *x*-direction? Explain.

3. **Predict.** Describe how the overall **speed** of the object has changed.

4. **Predict.** Draw the path of the puck after that 'tap'. Draw a vector, $\vec{v}_2$, representing the instantaneous velocity after the tap. You do not need to use a scale, but show the relative sizes of v_1 and v_2 carefully.

B: Off to the Races!

Consider a race between two pucks. **Each** starts with the same initial velocity to the north. The puck A travels on a level surface. The puck B moves on an incline tilted to the east. They race to the finish line. To help think about what happens, imagine that the puck on the incline receives a continuous series of taps to the east.



1. **Predict.** Imagine using a strobe light, flashing at regular time intervals, to take a picture of the pucks at three moments in time. Draw the path of each puck and its position for each flash.

2.

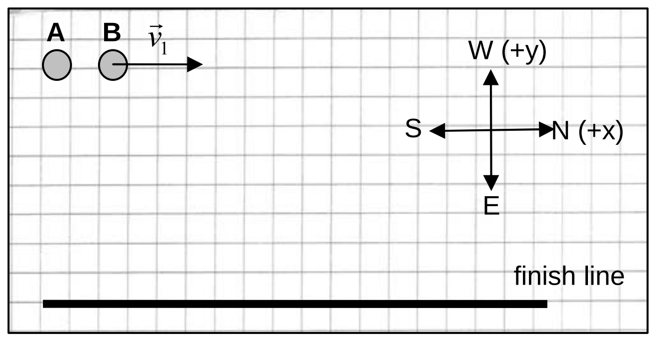
Predict. Describe how the velocity of the two pucks in the *x*-direction will compare.

3. **Predict.** Describe how the velocity of the two pucks in the *y*-direction will compare.

4. **Predict.** Based on your answers to questions 2 and 3 above, which puck will cross the finish line first?

C: Rematch!

Consider another race. **Both** pucks are on the incline tilted east. The puck on the left starts from rest, the puck on the right has an initial velocity north.



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

2. **Predict.** Imagine using a strobe light, flashing at regular time intervals, to take a picture of the pucks at three moments in time. Draw the path of each puck and its position for each flash.

3. **Predict.** Compare the motion of the two pucks at the time they reach the east edge of the grid.
   a. Which puck has traveled a greater distance? Explain.

   b. Which puck has reached a greater speed? Explain. Don't assume anything about time!

4. **Predict.** Which puck will cross the finish line first? Explain carefully how the factors of distance and speed affect the result.

SPH4U: Vector Components

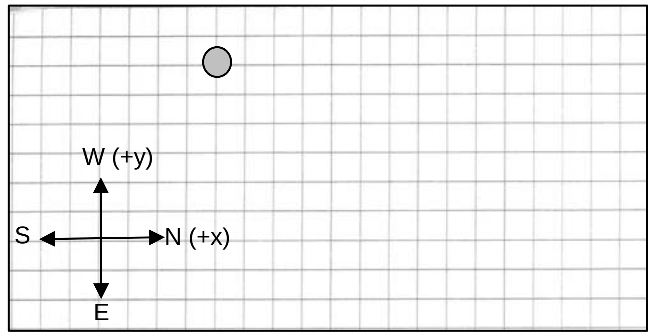
Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

How do we analyze the curving motion of the puck on the ramp? We need to develop new vector techniques for two-dimensional motion. Here we go!

A: The Component Triangle

In yesterday's experiments, careful measurement were made by a student who found that the puck moved through a displacement of 4.0 m [N 30° E].

1. Draw this vector on the grid starting from the image of the puck and label it $\Delta\vec{d}$. The grid 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**. Use the scale of 1.0 cm = 1.0 m for the position-space.



2. During the 2.0 seconds of its motion, the puck moved both in the *x*- and *y*-directions. Draw a right-angle triangle on the grid using $\Delta\vec{d}$ that shows how far the puck travelled in those directions. We will call this the *component triangle*. Draw arrowheads on each side of the triangle.

3. Use a ruler and make a measurement to determine how far the puck travelled each direction. Don't forget errors!
   a) *x*-direction
   b) y-direction

A *vector* is a quantity with two parts: a magnitude (size) and direction and is usually notated with a vector sign on top ($\Delta\vec{d}$, $\vec{v}$). When we want to refer to the magnitude of the vector only, we write $|\vec{v}|$ in absolute value signs. However, out of convenience, if it is understood that the quantity involved is a vector, we usually write just *v* to indicate the magnitude. Note that the magnitude of a vector is always a positive quantity. A vector can always be determined from the values of its *components*. The two small sides of the triangle you drew in question 2 represent the components of that vector which we can call Δd_x and Δd_y . The components are written as scalar quantities without a vector sign. Be sure to use a sign convention to show the direction of the components - make the values of the components either *positive* or *negative*.

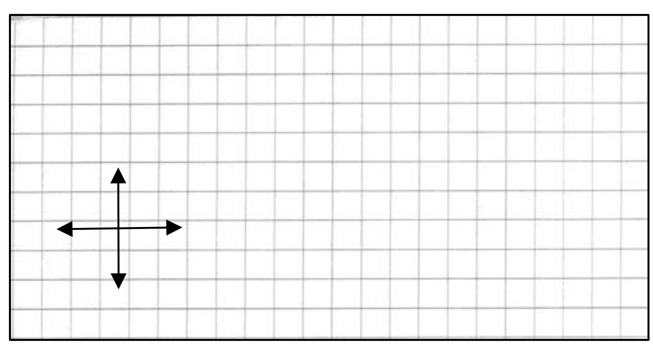
4. Write down the components you found for $\Delta\vec{d}$.

Δd_x = Δd_y =

B: Constructing Vectors

Now we will draw a different kind of diagram. The grid now 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**. It no longer indicates anything about the object's position or displacement.

1. Draw the velocity vector, $\vec{v}$ = 2.0 m/s [N 30° E] on the grid using the scale 1 cm = 0.50 m/s. Label the vector and construct its component triangle.



2. Use the Pythagorean Theorem to find an equation that relates the magnitude of $\vec{v}$ to the value of its *x*- and *y*-components v_x and v_y.

3. Use your diagram to directly measure the values of the components of $\vec{v}$

v_x = v_y =

4. Use the measured values of v_x and v_y to calculate the magnitude, v, of vector $\vec{v}$. How does this calculated value compare to the original magnitude? (Did you remember to include errors?)

5. Explain how we can use the sine and cosine functions to find v_x and v_y when we know v and the angle θ inside the triangle at the tail of the vector $\vec{v}$. (Note: Do **not** memorize these expressions! Always deduce them from your component triangle.)

6. Use the angle at the tail of $\vec{v}$ and the given magnitude of $\vec{v}$ to calculate the values of v_x and v_y. How do these values compare with those you measured directly for v_x and v_y?

7. Explain how we can find the angle θ from the components v_x and v_y and the inverse tangent function.

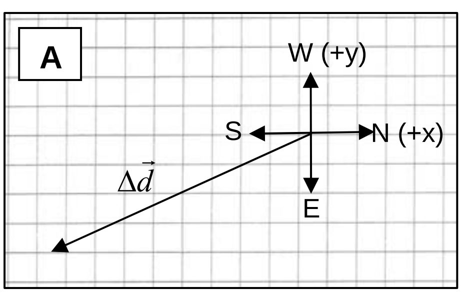
8. How does the calculated value of the angle θ compare with the original value? (Just estimate an error here!)

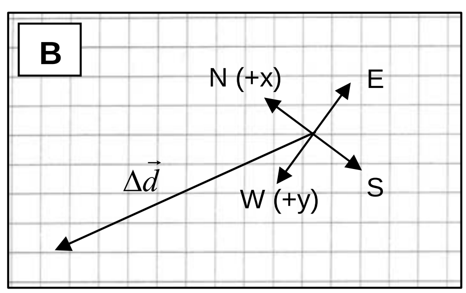
9. If a vector was reversed – flipped to the opposite direction – how would the values of the components change?

C: Summary

1. Explain how to construct a complete vector if you are given its two components.

2. The same displacement vector $\Delta\vec{d}$ is shown to the right along with two different coordinate systems A and B. Complete the chart below using measurements from the diagrams. Scale: 1.0 cm = 10.0 cm

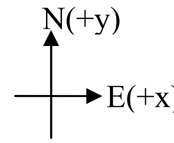




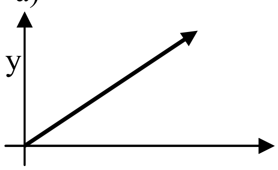
	Coordinate System A	Coordinate System B
$\Delta\vec{d}$ = _______ cm [ ]		
Angle with respect to the x-axis		
x-component		
y-component		

SPH4U: Vectors and Components

1. Find the components of each vector with respect to the given coordinate system. Be sure to use the given sign convention.



a)

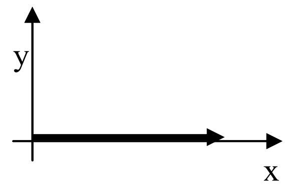


$\vec{A}$ = 30 m [N 40° E]

A_x =

A_y =

b)

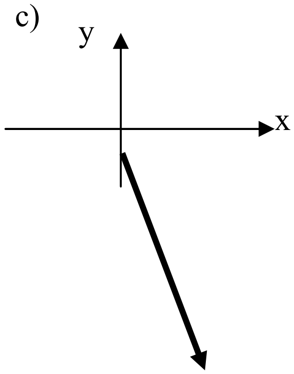


$\Delta\vec{d}$ = 20 km [E]

Δd_x =

Δd_y =

c)

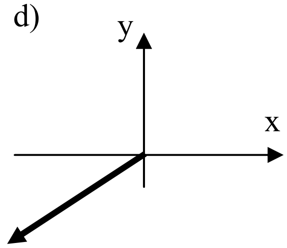


$\vec{F}$ = 45 N [S 20° E]

F_x =

F_y =

d)



$\vec{v}$ = 7.8 m/s [S 50° W]

v_x =

v_y =

Answers: (19 m, 23 m), (20 km, 0), (15 N, -42 N), (-6.0 m/s, -5.0 m/s)

2. Given the following components and sign convention, reconstruct the original vectors. Sketch the vector diagram showing the addition of the components into the resultant vector.

a) Δd_x = 300 m, Δd_y = 400 m, $\Delta\vec{d}$ =

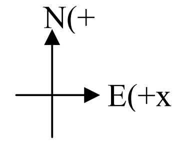
b) v_x = -12.4 m/s, v_y = 10.0 m/s, $\vec{v}$ =

c) a_x = 3.5 m/s^2, a_y = - 1.0 m/s^2, $\vec{a}$ =

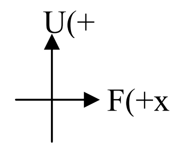
d) F_x = -549 N, F_y = -1007 N, $\vec{F}$ =

Answers: 500 m [E 53° N], 15.9 m/s [W 39° N], 3.6 m/s^2 [E 16° S], 1150 N [W 61° S]

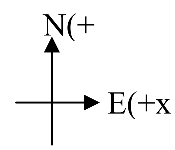
3. For each example below, use the following coordinate system to resolve the vector into components.

a) $\vec{F}_n = 20$ N [N 30° W]	b) $\vec{v}_1 = 50$ m/s [E 45° S] 
c) $\vec{a} = 1.5$ m/s^2 [S 80° W]	d) $\Delta\vec{d}_t = 3.0 \times 10^4$ m [N 10° E]

5. For each example below, use the following coordinate system to resolve the vector into components.

a) $\vec{F}_n = 1.40$ N [F 60° D]	b) $\vec{v}_2 = 250$ m/s [U 40° B] 
c) $\vec{a} = 9.8$ m/s^2 [D 20° F]	d) $\Delta\vec{d}_1 = 180$ km [U 82° F]

6. Reconstruct each vector using the given components and coordinate system.

a) $\Delta d_x = 20$ m, $\Delta d_y = -15$ m	b) $F_x = -160$ N, $F_y =$ 300 N 
c) $v_{1x} = 32$ m/s, $v_{1y} = -45$ m/s	d) $F_{tx} = 2.25$ N, $F_{ty} = 3.0$ N
e) $a_x = -4.95$ m/s^2, $a_y = -3.05$ m/s^2	f) $p_x = -40$ kg m/s, $p_y = 57$ kg m/s

SPH4U: Projectiles!

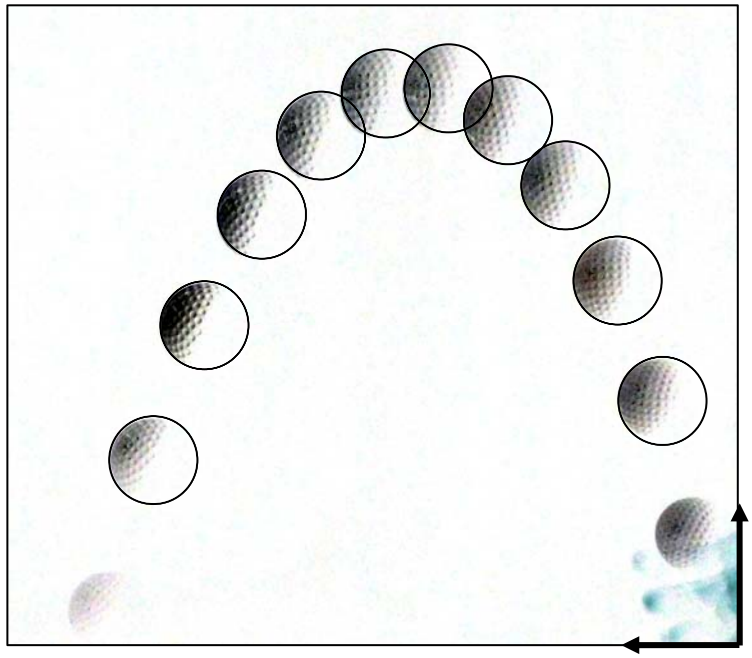
Recorder: ________________
Manager: ________________
Speaker: ________________
0 1 2 3 4 5

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

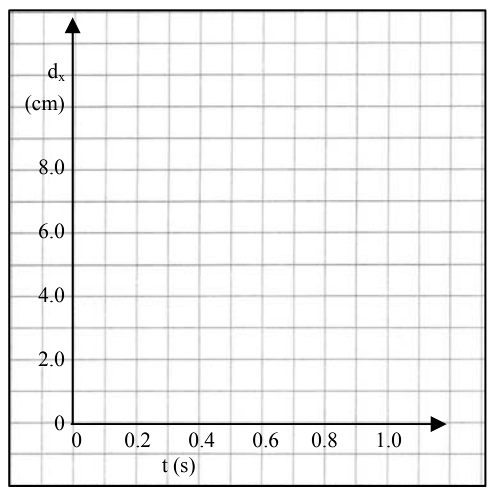
1. **Observe.** Choose a convenient reference point on the ball to help track its motion. Measure the *x*- and *y*-components of the position of the ball at each moment in time. The coordinate system for your measurements is drawn on the picture. The strobe light for the photo flashed at 10 Hz. Complete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

Image No.	t(s)	d_x (cm)	d_y (cm)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			



B: Horizontal Motion

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



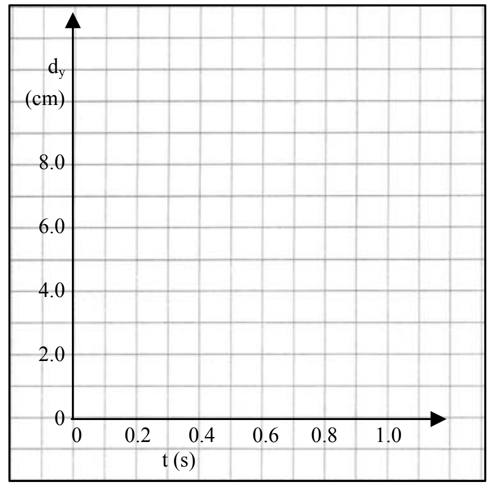
2. **Reason.** Refer to the pattern of data represented in the graph. What type of motion does the projectile experience in the *x*-direction?

3. **Analyze.** Use an appropriate graphical technique to determine the horizontal component of the velocity, v_x.

4. **Represent.** Use the graph to help create an equation that represents the horizontal position of the ball. Be sure to include units and don't use the symbols *x* and *y*!

5. **Reason.** Use the data of the graph to explain whether there is any *significant* evidence for forces acting in the horizontal direction? What can we conclude about the effects of air resistance?

6. **Apply.** If the ball moved for a total 5.0 s, what would its horizontal position be?

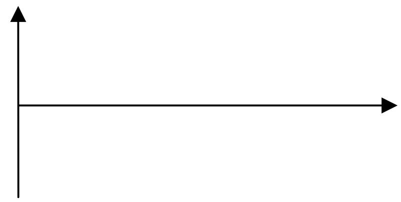


Part B: Vertical Motion

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

2. **Reason.** Refer to the pattern of data in the graph to help explain what type of motion the ball experiences in the vertical direction.

3. **Explain.** A student says that he is not sure why the graph for question 2 represents acceleration downwards. Explain without referring to any forces.



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

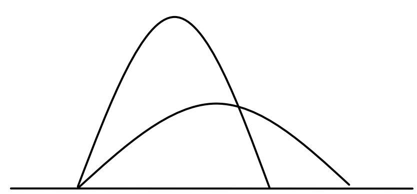
C: Projectile Motion

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 projectile 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. We will test this using a simulation.



4. **Speculate**. How might our understanding of projectile motion change if air resistance **is** an important factor?

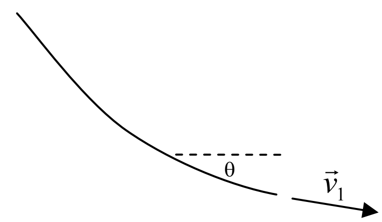
SPH4U: Projectile Problem Solving

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

The key idea which allows us to solve projectile problem is the independence of 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. When we set up our work, it is helpful to organize the givens into separate groups for the horizontal and vertical aspects of the problem. 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].

A: The Ski Jump

The ski jump is an exciting and death-defying event that turns humans 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 speed of 26 m/s. What is hard to notice from pictures is that the launch angle is **below** the horizontal! For the Vancouver hills, the angle was 11.25^o below the horizontal.

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. Include a sign convention. Find the components of any known vectors.

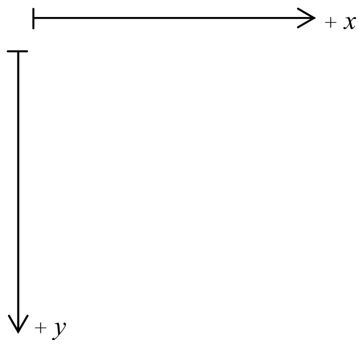
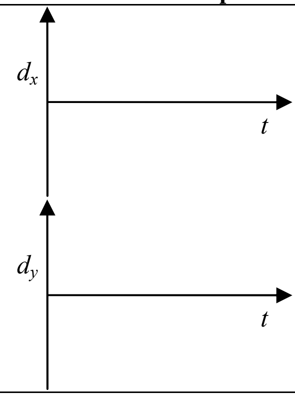
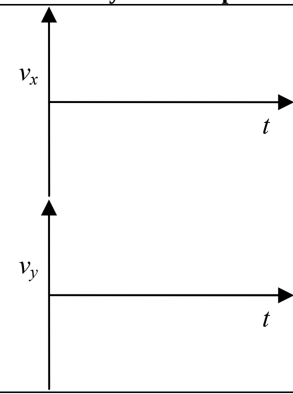
Horizontal	Vertical
v_x =	v_{1y} =
Δd_x =	v_{2y} =
a_x =	a_y =
Δt =	Δd_y =
	Δt =

2. **Explain.** Explain what steps are involved in finding the jumper's vertical velocity after a time interval Δt.

3. **Solve.** Determine the jumper's **total** velocity vector after 1.8 s of flight.

4. **Evaluate.** Is your result reasonable (size, units, direction)? Explain.

5. **Represent**. Draw a motion diagram and sketch the d-t and v-t graphs for the *x*- and *y*- components of the jumper's motion. Draw the vectors $\vec{v}_1$, $\vec{v}_2$ and $\Delta\vec{v}$ in such a way that we can see how they are related. Explain beside the vectors.

Motion Diagrams	Position-time Graphs	Velocity-time Graphs	Vectors
			

6. **Explain.** The jumper travels beyond the 1.8 s and soon lands after descending a certain vertical displacement Δd_y. Based on the starting information of this problem, explain how to find the horizontal displacement of the jumper.

7. **Calculate.** The jumper descends 35.8 m. How far horizontally did she travel?

8. **Reason.** Emmy says, "I think the calculation above would have been easier if we had used the fact that $v_{2y} = 0$ since she has landed." Do you agree with Emmy? Explain.

9. **Reason.** In a completely different situation involving a ski jumper, the following equations were arrived at:

$d_x = (12.5\text{ m/s})\Delta t$ $\quad\quad$ $d_y = (10.3\text{ m}) + (12.5\text{ m/s})\Delta t + ½(-9.8\text{ m/s}^2)\Delta t$

Create a carefully worded textbook problem for these equations. Given your problem statement, a student should arrive at exactly those equations during the solution. Be creative!

B: 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 our work here, for simplicity, 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.

1. **Represent.** Sketch this scene and construct a list of horizontal and vertical givens. Include a sign convention.

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

3. **Explain.** Describe the steps necessary to solve this problem.

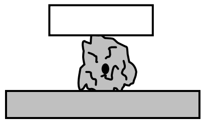
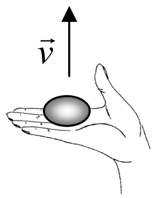
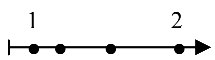
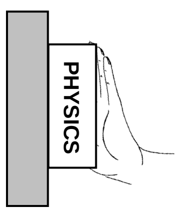
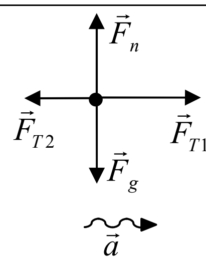
4. **Calculate.** Perform the calculation solve for your unknown quantity.

5. **Evaluate.** Interpret the result of your calculation and state the outcome of this problem.

6. **Calculate.** The ground under the ramp is level. How far horizontally does he travel while in the air?

Homework: Representing Forces

Complete the chart for each situation.

	Description	Sketch	Motion Diagram	Force Diagram	Newton's 2nd Law
1	A rock has a book resting on top of it. System = rock				
2	A tasty chocolate in your hand is moving upwards and is slowing down as it approaches your mouth. System = chocolate				
3					
4	System = Physics text				
5					
6					$F_{net\,x} = ma_x$ $F_f = ma_x$ $F_{net\,y} = ma_y$ $F_n - F_g = 0$
7	You hold a bag of groceries by the handle while standing in an elevator that starts from the ground floor and speeds up. System = bag				

SPH 4U: Representing Forces

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

A force diagram (FD) is a tool that helps us understand the total effect of all the forces acting on a system. There are a few steps that you should **always** go through when you draw a FD.

- Identify the object or objects of interest – they will we called the system.
- Model the system as a point-particle where we imagine all its mass is compressed into a single point.
- Ask the question: “At this moment in time, what objects are interacting with the system?” Draw a vector arrow representing each force associated with the 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 whenever possible.
- Draw a coordinate system that lines-up with the acceleration. The directions of the arrows are understood to be the positive directions.

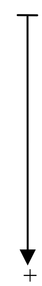
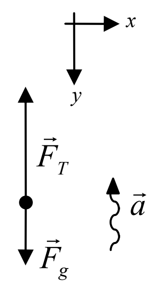
A: Lowering the Ball

Consider a ball being lowered on a string – the ball is the system. As it lowers, it slows down.

1. **Reason.** At this moment in time, what objects are interacting with the system? Explain.

2. **Represent**. Draw a motion diagram for the ball.

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

Motion Diagram	Force Diagram	Newton’s 2nd Law
		$F_{net\,x} = ma_x$ $F_{net\,y} = ma_y$

4. **Reason**. Does the motion diagram agree with the force diagram? Explain.

Newton’s 2nd Law: 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 scalar equations that represent the *x*- and *y*-components of the net force. Make sure you always follow these steps:

- Choose a sign convention for the coordinate system, usually with the direction of acceleration as positive.
- Write the scalar equation using the **force sign convention**.

The Force Sign Convention: When we write a scalar equation involving forces, the force symbols, such as F_g, are all positive quantities. Show the directions of the forces by using a sign convention and adding or subtracting the appropriate magnitudes. For example: $ma_x = F_n – F_w$, where F_n and F_w would be positive values and a_x could be either positive or negative depending on the sign convention.

5. **Represent.** Complete the two scalar equations for Newton’s 2nd Law in the box above. Make use of any quantities that equal zero. In the future, if all the quantities in an expression are zero, we will not bother writing it.

B: The Skydiver!

A skydiver is falling at a constant speed after her parachute deploys.

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

2. **Reason.** Emmy asks, “How can the skydiver be moving if her acceleration is zero?” Offer an explanation to Emmy.

Motion Diagram	Force Diagram	Newton’s 2nd Law

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.

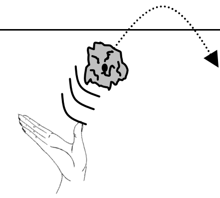
C: The Rock Toss

A student throws a rock which travels in an arc through the air. The rock was released and is now travelling upwards.

1. **Reason.** At this moment in time, what objects are interacting with the system of the rock?

2. **Represent.** Complete the chart to the right for the system of the rock.

3. **Reason.** A student asks, "Why isn't there a force pointing at an angle, in the direction the rock is moving - why else would it be going that way?" Offer an explanation to the student.

Sketch	Force Diagram	Newton's 2nd Law
		

4. **Reason.** How would the force diagram look different if the rock was thrown straight up in the air? What information can we **not** find from a force diagram?

D. The Skater

A skater glides along a smooth, level and icy surface without speeding up or slowing down.

1. **Represent.** Complete the chart to the right for the system of the skater.

2. **Explain.** Albert says, "I'm just not sure if friction should be included in the force diagram. How should we decide?" Explain to Albert how.

Force Diagram	Newton's 2nd Law
Motion Diagram	

3. **Explain.** Isaac asks, "How can the skater be moving without slowing down when there is no forwards force acting on her?" Explain to Isaac how.

E: The Finale

A wagon is being pulled along a rough surface by a horizontal rope. It is gradually slowing down.

1. **Represent.** Complete the chart to the right for the system of the wagon.

2. **Explain.** How did you decide how long to draw the force vectors in your force diagram? Explain.

Force Diagram	Newton's 2nd Law
Motion Diagram	

SPH4U: Forces in 2-D

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

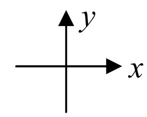
For these investigations you will need: two 10-N spring scales, one dynamics cart, and one protractor.

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.

A: Tilted Forces

The cart experiences a force, $\vec{F}_1$ = 5 N [Left] and a force $\vec{F}_2$ which is directed [Right 30° Up]. The cart remains at rest on a level surface.

Force diagram



Component triangle of $\vec{F}_2$

1. **Predict.** How do you think the magnitude of $\vec{F}_2$ compares with $\vec{F}_1$? Explain.

2. **Test.** Model this situation using two spring scales for $\vec{F}_1$ and $\vec{F}_2$, and a protractor. Measure the size of $\vec{F}_2$ and record it here. (Don't forget errors!)

3. **Represent.** Draw a component triangle for $\vec{F}_2$. Which side of the triangle represents the spring scale measurement?

4. **Predict.** According to your understanding of the situation, **w**hat should the value of the *x*-component of F_2 equal? Explain.

5. **Test**. Calculate the components of $\vec{F}_2$ based on your measurement. Do the results agree with your prediction? (Don't forget errors!)

When you draw components on a force diagram, use a different colour of type of line so the component is cannot be mistaken as a separate force.

6. **Represent.** Write an equation for Newton's 2nd Law in the *x*- and *y*-directions. Show the trigonometry for any components.

7. **Reason.** Issac 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.

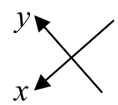
8. **Predict.** Predict the size of the normal force using Newton's 2nd Law.

9. **Test.** Place the cart on a triple beam balance scale and try to recreate the vertical forces in this situation (that is, only exert the vertical component of F_2). Scales can only measure forces, but this one gives a reading in grams. Calculate the equivalent reading in newtons. (Hint: the force the scale measures is supposed to be equal to the force of gravity). Which force is the scale actually reading?

B: Forces on a Tilt

The cart is at rest on a surface inclined at 30°. It is held in place by a force, $\vec{F}_a$, that is parallel to the incline. Later, you will use the incline set up at the front of the room.

Force diagram



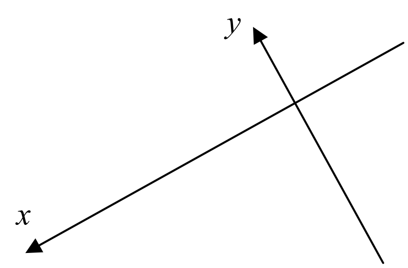
1. **Represent.** Draw the force diagram for the cart.

2. **Reason.** Which forces, or components of a force, act in each direction? Note the special coordinate system chosen!

+ x	- x	+ y	- y

3. **Reason.** Which forces, or components of a force, balance each other?

4. **Reason.** Which force or component of a force pulls the cart down, along the incline?



5. **Represent.** Draw the component triangle for the force of gravity $\vec{F}_g$ relative to the tilted coordinate system. Locate the 30° angle in the triangle. What are the magnitudes of the components of $\vec{F}_g$? Use sin or cos.

6. **Predict.** Based on your considerations above, predict the size of $\vec{F}_a$.

7. **Test.** Use the incline at the front of the class to measure the magnitude of $\vec{F}_a$. How does this compare with your prediction? (Did you remember errors?)

8. **Represent.** Write an equation for Newton's 2nd Law in the x- and y-directions.

9. **Predict.** Explain how F_a would change if the angle of the incline is increased. Test this.

10. **Calculate.** Determine the magnitude of $\vec{F}_n$ from your equation.

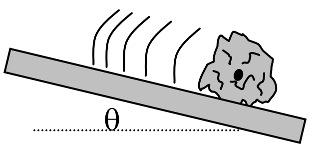
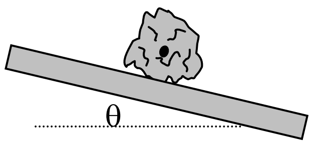
11. **Reason.** Explain how F_n would change if the angle of the incline is increased. Why does this "make sense"?

SPH4U: Understanding 2-D Forces

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

A: Rocks on Inclines

For each situation, draw the force diagram and write out a complete expression for Newton's 2nd Law in the *x*- and *y*-directions.

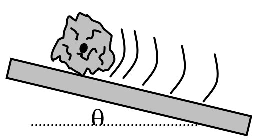
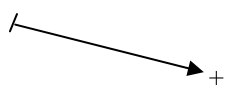
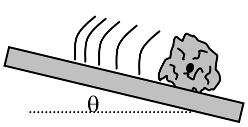
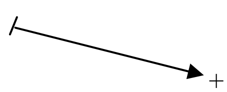
A rock is sliding without friction. 	Force Diagram	Newton's 2nd Law
Friction prevents the rock from sliding. 	Force Diagram	Newton's 2nd Law

1. **Explain.** How did you choose your coordinate system for these two examples?

B: The Rough Incline

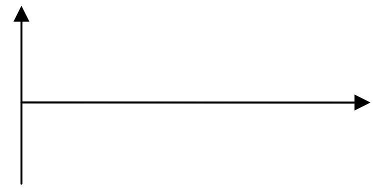
A rock slides up and then down an incline. There is a constant force of friction, but not quite enough to prevent the rock from sliding back down.

1. **Represent.** Complete the chart below.

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

2. **Reason**. Albert says, "The magnitude of the rock's acceleration will be the same when it is going up the incline as when it is going down. After all, it's the same forces at work." Do you agree or disagree with Albert? Explain.

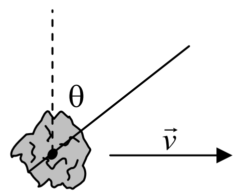
3. **Predict**. How will the brick's greatest speed up the incline compare with its greatest speed down the incline (i.e. the speeds near the bottom)? How will the time for the trip up compare with the time for the trip down? Explain. We will test this as a class. Sketch a *v*-*t* graph for the brick.



C: The Floating Rock

A rock is tied to a string. Emmy claims, "I can pull the rock with the string at an angle, like this, so it moves **horizontally** through the air." Isaac replies, "That's not possible, even for a short period of time. The forces simply don't work out properly."

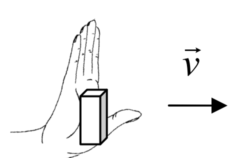
1. **Reason.** Whom do you believe? Explain with the assistance of the force diagram and equations.

Can the rock travel horizontally?	**Force Diagram**	**Newton's 2nd Law**
		

D: The Magic Eraser

Enrico says, "Look! I can make my eraser stay in place against my vertical hand without me holding on to it!" Marie says, "Nonsense! Gravity is guaranteed to pull it down."

1. **Reason.** Who do you agree with? Explain.

Can the rock "stick" to a person's hand?	**Force Diagram**	**Newton's 2nd Law**
		

2. **Reason.** How does the size of the normal force compare with the size of the force of gravity in this case? Explain.

SPH4U: Newton's Third Law

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

A: The Forces as Interactions

Throughout our unit on forces, we have been making use of the term *interaction*. When two objects affect one another, we say that they *interact*. We have also noticed that these interactions come in the form of a push or a pull on the objects which we call *forces*.

1. **Reason**. We have studied many types of interactions already in gr. 12 physics. What are at least four types of interactions that we have come across thus far in gr. 12 physics?

This brings us to a very important idea. Whenever two objects interact, they exert forces on one another. What is important to understand is that these two forces are parts of a **single interaction**. Because of this fact, the two forces, which we will call a *3rd law force pair*, share some important characteristics. The forces in a 3rd law force pair:

- have the same magnitude
- point in opposite directions
- are the same type (gravitational, normal, etc.)
- arise and act simultaneously

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 simply 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.

Sketch	Force Diagram

1. **Represent**. Draw a sketch and a force diagram for the system of the book.

To show better the details of an interaction, we can use a more specific force notation. For example the earth interacts with the textbook gravitationally and we can symbolize this as: $\vec{F}_{g\ E-B}$, which reads: "the force of gravity due to the **earth** acting on the **book**". Using this notation, we can write Newton's 3rd Law as: $\vec{F}_{A-B} = -\vec{F}_{B-A}$ with the understanding, mentioned above, of the force-pair's characteristics.

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

Note that if you have done this correctly, all the forces on one force diagram will end with the same subscript. Double check this every time you use this notation.

3. **Reason.** Issac 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.

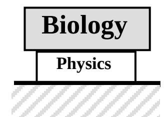
4. **Reason**. Emmy says, "Is it just a coincidence that gravity and the normal force have the same size? Why do they?" Explain to Emmy why.

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

C: The Stack O' Books

Your homework is piling up – sitting on top of your slender physics text is your massive biology text.

1. **Represent**. Draw a force diagram for each text. (Hint: you should draw five forces in total!) Whenever we study the forces of more than one object, use the detailed force notation introduced above.

Sketch	Force Diagram	Force Diagram
		

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.

2. **Reason**. Which forces are contact and non-contact forces?

3. **Test**. Marie says, "In this situation, the weight of the biology text acts on the physics text." Test this assertion. Use your hand in the place of the physics text. Lower the biology text (or other, suitable book) onto your hand. Based on your understanding of contact forces, decide whether Marie is correct and justify your conclusion.

4. **Reason**. Are there any 3rd-law force pairs appearing in the two diagrams? If so, indicate these with a small "×" on each member. If there is a second pair use a "××" on each member, and so on.

5. **Reason**. Rank the magnitude of the forces appearing in the two force diagrams from smallest to largest. Explain your ranking.

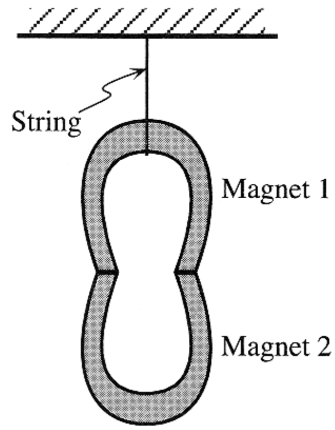
6. **Represent**. Based on your ranking of the magnitudes of the forces, do you need to make any modifications to your two force diagrams? Explain why or why not.

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. **Summarize.** Based on today's investigation and the rest of our work in gr. 12 physics, what can we conclude about the size of the normal force compared with the force of gravity? What is the best way to determine the size of the normal force?

Homework: Contact and non-contact forces

A. A magnet is supported by another magnet as shown at right.



1. Draw a free-body diagram for magnet 2. The label for each of the forces on your diagram should indicate:

   - the type of force (*e.g.*, gravitational, normal),
   - the object on which the force is exerted, and
   - the object exerting the force.

2. Suppose that the magnets were replaced by stronger magnets of the same mass.

   If this changes the free-body diagram for magnet 2, sketch the new free-body diagram and describe how the diagram changes. (Label the forces as you did in part 1 above.) If the free-body diagram for magnet 2 does not change, explain why it does not.

3. Can a magnet exert a non-contact force on another object?

   Can a magnet exert a contact force on another object?

   Describe how you can use a magnet to exert *both* a contact force and a non-contact force on another magnet.

4. To ensure that you have accounted for all the forces acting on magnet 2 in parts 1 and 2:

   List all the non-contact forces acting on magnet 2.

   List all the contact forces acting on magnet 2. (*Hint:* Which objects are in *contact* with magnet 2?)

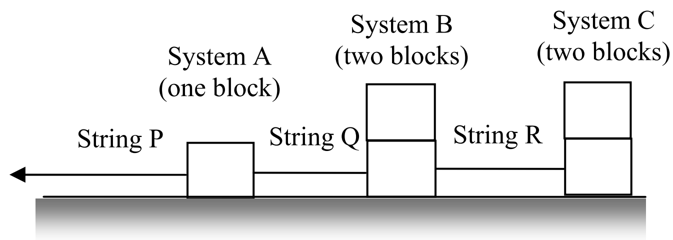
from McDermott, L. *Tutorials in Introductory Physics.* Prentice Hall, 2002

SPH4U: Composite Objects

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

Five *identical* blocks, each of mass *m*, are pulled across a table by a steady force as shown. Use the approximations that the table is frictionless and the strings are massless and do not stretch. You may assume the blocks are stuck together.

1. Compare the motion of each of the systems A, B, and C.



2. Draw and label the separate free-body diagrams for the separate systems A, B, and C. Indicate the mass of each system. Draw an acceleration vector for each.

System A	System B	System C
m_a =	m_b =	m_c =

3. Rank in increasing size the magnitudes of the *net forces* on systems A, B, and C. Explain.

4. Draw a free-body diagram for a two new systems. System D represents system B and C together. System E represents all the five blocks. Remember, only draw external forces! Indicate the mass of each system.

System D	System E
m_d =	m_e =

5. How does the acceleration of system D and E compare with that of A, B, and C? Explain.

6. Which system yields the easiest free-body diagram if you want to find the force of tension in strings P, Q and R?

7. Rank in increasing size your predictions for the magnitudes of the three tension forces.

8. Consider a situation where m = 1 kg and F_{TP} = 15 N. Find the size of F_{TQ} and F_{TR}.

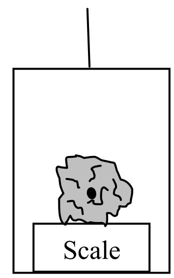
SPH4U: Weight and Acceleration

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

In the world of physics, weight has a simple definition: Weight = $F_g = mg$. Where the gravitational field strength, $g = 9.8$ N/kg. This sometimes differs from our everyday experience of weight which we associate with the reading of a bathroom scale. To distinguish this, we will call the scale force the **apparent weight**. We have already learned that this reading is actually a measurement of the force required to support the object (often the normal force). You need one spring scale, one mass (0.5 or 1 kg).

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. You place a 2.0 kg rock on a bathroom scale that gives readings in newtons. You haven't pushed any buttons yet and you look down at the scale.



FD

1. Draw a FD for the rock in the elevator according to the description above.

2. A student, Albert, suggests: "There should be another force on the FD showing the effect of the cable." Respond to Albert.

3. Show how you can use Newton's 2nd law ($F_{net} = ma$) to determine the apparent weight of the rock.

B. The Trip 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. You notice the reading on the scale changes.

1. Isaac says, "In this situation we need to add another upwards force to the free body diagram since the rock is now accelerating upwards." Do you agree or disagree with Isaac? Explain.

2. Explain how the reading of the scale will change. Support your explanation with some simple observations using your spring scale and mass.

3. The elevator is accelerating at a rate of 1.5 m/s^2. Use Newton's 2nd law to determine the apparent weight of the rock.

4. Based on this discussion, why is it important to distinguish between weight and apparent weight?

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

5. How has the motion of the elevator changed? Use your spring scale to help explain.

The elevator travels past the 19th floor. You notice another change to the scale reading as the elevator is slowing down.

6. A student, Marie, comments, "I think the upwards force must still be larger than the downwards, or else the elevator would not be moving upwards." Respond to Marie.

7. Explain how the reading of the scale will change. Support your explanation with some simple observations using your spring scale.

8. The elevator slows at a rate of 3.4 m/s^2. Determine the apparent weight of the rock.

9. Explain in general how apparent weight is related to the acceleration of an object.

C. A Strange Elevator

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

1)

2)

SPH4U: Frames of Reference

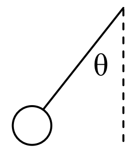
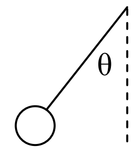
Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

Your friend is standing on a bus that is travelling east and speeding up at a uniform 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.** Draw a motion diagram for the ball relative to the frame of reference while the bus accelerates in a steady way.

2. **Represent.** Draw a FD for the ball from each frame of reference. Do not include fictitious forces yet. Include an acceleration vector!

3. **Reason.** There is a contradiction within one of the force diagrams. Explain carefully.

Earth frame	Bus frame
	
1.	
2.	

4. **Represent.** Draw a modified FD for your friend's frame of reference. Add a fictitious force, F_{fict}, such that FD agrees with her description of the ball's motion. How does the direction of the fictitious force compare with the acceleration of the bus, a_b, as measured in your frame?

New FD

5. **Summarize.** Think of other situations you have been accelerated. Except when in free fall, we feel as is 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?

6. **Analyze.** From the Earth frame of reference, use Newton's 2nd law to write an expression that allows you to determine the acceleration a_b in terms of θ and g.

7. **Analyze.** We want to find an expression for the size of the fictitious force, given m and a_b. Write out Newton's 2nd law in the x-direction for each frame and use the two results!

8. **Summarize.** The result you found above is a general result that applies to the size of all fictitious forces. State this in a succinct way.

SPH4U: Tension and Pulleys

How do strings work? Let's create a model for what happens inside a string and summarize a string's properties.

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

A: String Theory

You need three identical spring scales and a mass (0.5 or 1.0 kg). Connect all three spring scales into a chain. Each scale represents a piece of "string material" and the spring connections represent the forces that act between the pieces of string material.

1. **Describe**. Hold the spring scales horizontally across your table in such a way that they each show a reading. Explain carefully how you accomplish this.

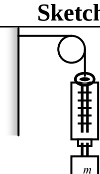
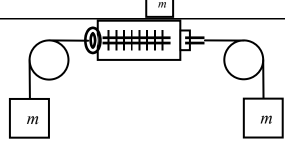
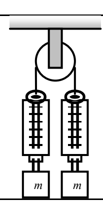
2. **Observe**. In the situation above, how do the readings of each scale compare? What happens to the readings when you pull harder?

3. **Represent and Reason.** Draw a force diagram for each spring scale as a separate system. How do the individual forces on each system compare? How do the net forces experienced by each system compare?

4. **Summarize**. Devise a "theory of strings" that explains what happens inside a string that is under tension and how the forces inside the string compare.

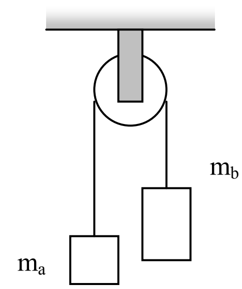
B: Testing the String Theory

1. **Predict and Test.** For each situation below, use your string theory to predict the scale readings. You will need two pulleys. Make measurements in each situation and explain whether your theory is supported or refuted. Note that ideal pulleys only change the direction of a tension force and not its magnitude.

	Sketch	FD for Spring Scale	Prediction	Conclusion
1				
2				
3				

C: The Atwood Machine

An Atwood machine consists of two weights 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 weights have equal masses. You give a gentle push to one weight. Predict the motion of the weight **after** it leaves contact with your hand.

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

3. **Predict.** The mass of weight A is now greater than weight B. Predict the motion weight A after it is released. How will the motion of the two objects compare?

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

5. **Represent.** Draw a FD for weight A and for weight B. ($m_a > m_b$). Choose your sign conventions so they agree with the acceleration of each object!

6. **Reason.** For the FDs, do you need to use a different symbol for the magnitude of the acceleration of weight A and weight B? What about the forces of tension and gravity acting on each mass? Explain.

Weight A	**Weight B**

7. **Predict**. How will the magnitude of the force of tension compare with F_{gA} and F_{gB}? Explain.

8. **Represent.** Write a complete expression for Newton's 2nd Law for each weight. Be very careful with your notation!

9. **Calculate.** Algebraically eliminate F_T from the above two equations and solve for the acceleration of the masses. Use the masses from the Atwood machine set up in the classroom and solve for the acceleration.

10. **Test.** Now go back and solve for the force of tension. How does this result compare with your prediction? 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?

You need a friction box and a 1 kg mass.

1. **Represent.** Place the box on the flat palm of your hand and place the weight in the box so it doesn't slide around (use a piece of tape if necessary). Keep your hand completely horizontal and cause the box to speed up together with your hand. Draw a FD for the box-weight system while it is speeding up.

FBD

2. **Reason.** Marie says, "Wait a minute - I'm confused. I remember that an applied force is really just a normal force. Should I draw a *horizontal* applied force on the force diagram?" Explain to Marie.

3. **Reason.** Emmy says, "Friction must point in the forwards direction." Albert responds, "That's not right. Friction opposes an object's motion. It should point in the backwards direction." Who do you agree with? Explain.

4. **Predict.** What would happen to the box if there was *no friction at all* between the box and your hand? Explain.

5. **Test.** Try this out with the equipment at the front of the class. Record our observations. What does friction prevent the two surfaces from doing?

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

B: Two Kinds of Friction

You need a **wood** dynamics cart and a spring scale (5N).

1. **Represent.** Place the friction box and weight on top of the cart. Keep the cart fixed in place. Exert a force on the box using the spring scale such that it slides along the cart's upper surface at a constant velocity. Draw a FD for the box while sliding.

FBD

2. **Explain.** Why does the spring scale reading give us the force of *kinetic friction?* Determine the size of the force of kinetic friction between the box and the cart.

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

The force of friction depends on the nature 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, $F_{fk} = \mu_k Fn$ and $0 < F_{fs} \leq \mu_s F_n$.

4. **Calculate.** Determine the coefficient of kinetic friction for the box and cart.

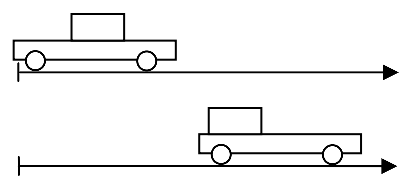
5. **Reason.** Imagine you repeat this experiment in an elevator accelerating upwards. Albert says, "I bet the value for μ will get smaller since μ depends on F_n." Emmy says, "The equation written as $\mu = F_f / F_n$ makes it look like μ depends on F_n, but is actually doesn't." Who do you agree with? Explain.

C: Friction Causing Motion

Place the box in the middle of the cart. Use the spring scale to pull **on the cart** and cause both the cart and box to move.

1. **Observe and Explain.** Exert a small, gentle force on the cart, causing both the cart and box to accelerate together. Describe the motion of the box. What force was responsible for the box's motion?

2. **Observe and Reason.** Repeat using a very large force so the box slips. Issac was watching with you and says, "Look at that. The box went backwards." Do you agree or disagree with Isaac? Explain using the sketches of the box and cart.



3. **Explain.** Another way of explain the observations from the previous question is through frames of reference. Describe the observations that would be made by an observer sitting on the cart and one at rest on the earth.

4. **Observe and Reason.** Repeat the exact same motion. What force was responsible for the box's motion?

5. **Reason**. Marie says, "This is a problem! Isn't friction supposed to oppose the motion of an object?" Explain to Marie.

6. **Observe and Reason.** In this situation, it is reasonable to state that the force of friction between the cart and the table is negligible. Make and describe a measurement that supports this statement.

7. Now we will draw three FDs while the cart and box are moving together (no slipping). Indicate any 3rd law force pairs that appear.

The box	The cart	The cart + box system

8. **Reason.** There is an upper limit to the acceleration of box. Use the x-component of Newton's 2nd law for the box to help explain why.

9. **Reason.** If we pull too hard on the cart, the box will begin to slip. We want to determine the largest force that we can exert on the cart without any slipping. Which FBD would be the simplest to use? Explain.

10. (*Homework*) **Calculate.** Determine the largest force that we can exert on the cart before the box starts to slip. (Hint: Use your reasoning from the two previous questions. Use $\mu_s = 0.6$)

D: Friction and the Ramp

You need a friction box, a 1 kg mass, spring scale and a track **(no retort stand!).**

1. **Observe and Calculate.** Determine the coefficient of static for the box on the **horizontal** track surface. There is a lot of error in this measurement, so record a high and low possible value for your measurement and calculate a high and low possible value for the coefficient. Show your work.

FD

2. **Reason.** Now draw a FD for the box at rest on an **incline**. Explain how each force changes when the angle of the incline increases. The *x*-axis is parallel to the incline.
   a. F_g :
   b. F_{gx} :
   c. F_{gy} :
   d. F_n :
   e. $F_{fs\ max}$:

3. **Predict.** Analyze the situation using Newton's 2nd law. What angle do you predict the box would start moving at? (Find a high and low value.) Do all your work algebraically and you will get a *very* simple expression.

4. **Test.** Call your teacher over to test your prediction. Record the angle at which it begins to slide. How does this compare with your prediction? Note that there are large sources of error in this investigation!

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. **Represent.** Have that person freeze in place as their back foot is pushing against the ground. This is a very difficult situation to model with a FBD, but being fearless, we will try! Draw a FBD for the back foot while walking. Include a force at an angle for the effect of the leg on the foot.

3. **Explain.** What force is pushing forward on the foot? Ultimately, this is the external force responsible for making you as a whole accelerate forward.

4. **Reason.** If this force disappeared, what would happen as we try to walk?

5. **Reason.** Isaac says, "According 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 by suggesting that we replace the earth with a dynamics cart.

SPH4U: Going in Circles?

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

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

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. **Observe.** Describe the velocity of the buggy when it drives along the level floor with no additional forces.

2. **Observe.** Attach a piece of string to the buggy – if it tends to flip, adjust the string angle. In the chart below, describe how the velocity (speed and direction) of the buggy changes when you exert a constant, horizontal force on the buggy in a direction: (a) parallel to its motion, and (b) perpendicular to the direction of the buggy's motion.

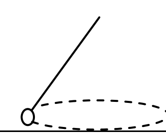
Forces Parallel	Forces Perpendicular

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

4. **Observe and Reason.** Make the buggy move in a circle with the string horizontal. Draw a FBD for the buggy from a head-on point of view at two different moments in time (as if you were lying on the ground at a moment when it was traveling directly towards or away from you).

a) Which objects interact with the buggy? b) What forces or components of forces balance? c) What is the direction of the net force experienced by the buggy?	FDB	FBD

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



a) Which objects interact with the circling object? b) What forces or components of forces balance? c) What is the direction of the net force experienced by the object?	FDB (head-on view)

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 Rule #1:

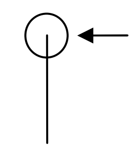
2. From your observations or from your own experience when you move in a circle you may have noticed other characteristics of forces in circular motion. Here are some other plausible provisional rules for circular motion:

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

Provisional Rule #3: *When an object moves in a circle, there must be a 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 two experiments we will look for evidence which supports or refutes these three rules.

3. **Predict and Test**. A hover puck is attached to a string. The hover puck is given a short push and is released. The end of the string is held fixed.
   (a) Predict how the puck will move **after** the push.



FBD

   (b) Test your prediction and describe the motion of the puck.

   (c) Draw a FBD for the puck **after the push** from a bird's eye view (from above).

   (d) Each rule makes a prediction about this situation (after the push) which is shown below. Based on your observations and your understanding of the forces, which rules are confirmed and which are refuted? If you think a force is present, you must explain what force it might be.

Rule #1	Rule #2	Rule #3
Prediction: There is a net force pointing towards the centre of the circular path.	**Prediction**: There is a force in the outwards direction (away from the centre)	**Prediction**: There is a force in the forwards direction (tangent to the circular path).
Conclusion:		

4. **Predict and Test.** A hover puck is initially moving in a circle due to a string. The end of the string is released.
   (a) Try this out and describe the motion of the puck after it is released.

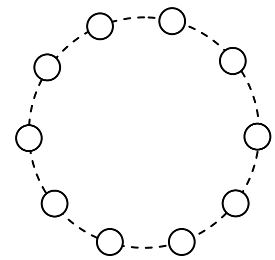
   (b) The only force that changed when the string is released is the inwards force of tension. Based on your observations and your understanding of the forces, which rules are confirmed and which are refuted? Explain briefly.

Rule #1	Rule #2	Rule #3
Prediction: If the net force is now zero, it will travel in a straight line.	**Prediction**: If there is an outwards force, it is still there, so it will travel directly outwards.	**Prediction**: If there is a forwards force, it is still there, so it should accelerate away.
Conclusion:		

5. **Reason.** Elevate one of the provisional rules to an official rule. Mention what uniform circular motion means.

Net Force and Uniform Circular Motion:

6. **Prediction**. Use your new force rule to explain how to cause the hover puck to move in a circle simply by using gentle taps from a metre stick. Illustrate the force of your taps in the diagram. As a class, we will test this out (move on for now).



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 with out 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**! Centripetal is simply a new category 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 are centripetal forces.

8. (*as a class*) **Observe and Explain.** Watch the simulation for the car travelling around a corner. As a passenger in the car, explain what is actually happening when we:
(a) slide across the seat

(b) are "pressed" against the car door

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. Explain how you can decide what the spring scale will read. Predict the spring scale reading and support this with the appropriate illustrations and equations.

2. **Predict.** Imagine you pull the mass to the side and release it such that it swings like a pendulum and moves along **a circular path**. Even though the speed of the pendulum changes, at the bottom of the swing our new rule still applies (think of the FBD at that moment). When the ball passes directly under the scale, will the scale reading be greater than, less than or equal to the reading at rest. Use the new force rule to come up with your prediction.

3. **Test.** Perform the experiment. Record the outcome and compare it to your prediction. Does it support or refute the new rule? Explain.

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

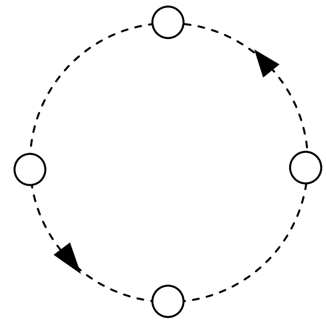
SPH4U: Centripetal Acceleration

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

Think back to our experiments in the previous investigation with the hover puck and string. In one case, we let go of the string and observed the motion of the hover puck. This gives us a hint about the instantaneous velocity of the puck at the moment it was released.

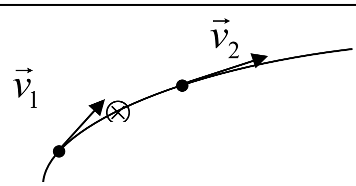


1. **Reason.** Draw an instantaneous velocity vector for the hover puck at the four moments in time shown in the diagram. When drawing instantaneous velocity vectors, they should appear **tangent** to an object's path.

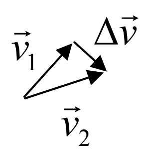
2. **Explain.** When an object moves in a circle at a steady rate, does the speed change? Does the velocity change? Explain.

B: Acceleration

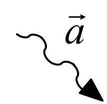
The technique explained below will help you estimate the average acceleration of an object during two-dimensional motion. In grade 11 you learned that adding vectors is done by drawing them tip-to-tail. To find the acceleration, we need to find a change in velocity, $v_2 - v_1$. Subtracting two vectors is done by drawing them **tail to tail.**



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



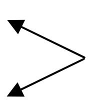
Redraw the velocity vectors tail to tail. Draw the change in velocity vector going from the head of v_1 to the head of v_2.

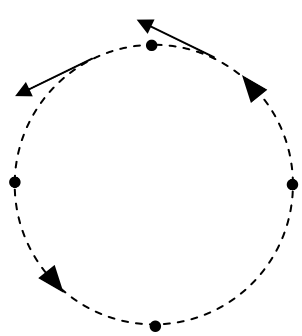


The acceleration, *a*, is in the same direction as the change in velocity, Δv, and has a magnitude $\Delta v/\Delta t$.

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.

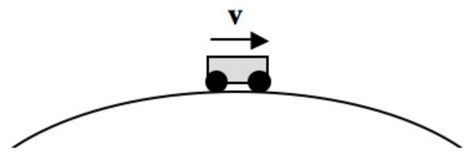




2. **Reason.** What is the pattern to the acceleration vectors found in the previous question?

An object moving in a circle experiences a **centripetal acceleration, a_c,** which points towards the centre of its circular path.

3. **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?



4. **Represent.** A physics buggy moves at a constant speed across the top of a circular hill, as shown in the illustration. In the chart below, use the vector subtraction technique to find the acceleration, draw a FBD, and explain whether the two results agree according to Newton's 2nd law.

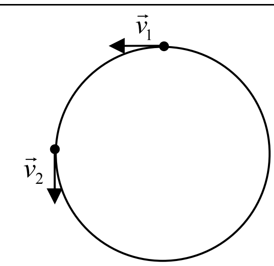
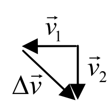
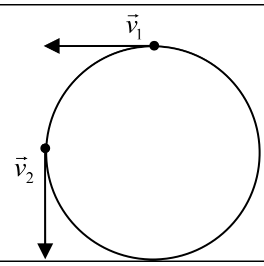
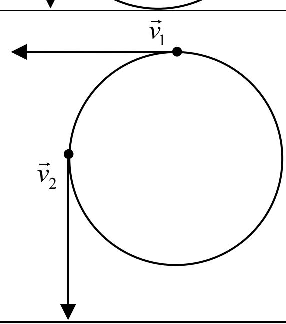
Vectors	FBD	Agreement?

5. **Apply.** Have you ever been in a situation like the one described above? What was the situation and what did it *feel* like?

D: Acceleration, Speed and Radius

Three different physics buggies travel at a constant speed along three identical circular paths. Buggy A moves with speed v, Buggy B with speed $2v$ and Buggy C with speed $3v$. Buggy A completes a ¼ trip in a time Δt and experiences a change in velocity Δv.

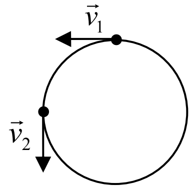
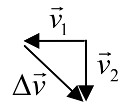
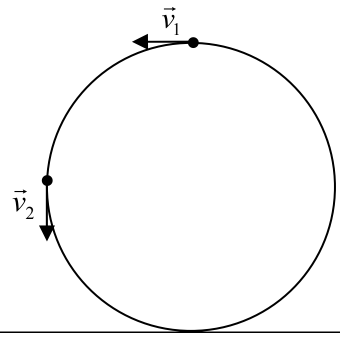
1. **Represent.** Use the vector subtraction technique to compare the centripetal accelerations of the three buggies.

	Illustration	Change in Velocity	Time Interval	Acceleration	Summary
Buggy A			For a ¼ trip: Δt	$a_A = \Delta v / \Delta t$	How does the magnitude of the acceleration depend on the speed? Write out a mathematical expression for this relationship.
Buggy B		Hint: How does this Δv compare with the first?	How does this Δt compare with the first?		
Buggy C					

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

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.

2. **Represent.** Use the vectors subtraction technique to compare the centripetal acceleration of each buggy.

	Illustration	Change in Velocity	Time Interval	Acceleration	Summary
Buggy A			Δt	$a_A = \Delta v / \Delta t$	How does the magnitude of the acceleration depend on the radius? Write out a mathematical expression for this relationship.
Buggy B					

3. **Reason.** Combine the two results above and write a general expression for the magnitude of the acceleration during uniform circular motion.

E: Test the Acceleration Expression

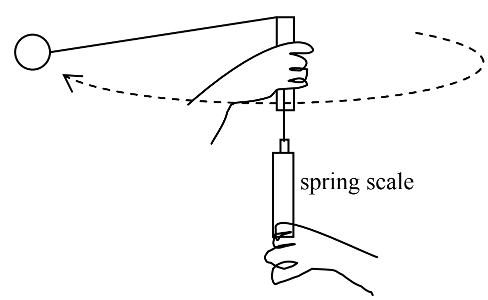
There are two other ways of writing your general expression for the centripetal acceleration: $a_c = 4\pi^2 r f^2 = 4\pi^2 r/T^2$ where f is the frequency and T is the period of the circular motion. Recall that $f = 1/T$.

1. **Reason.** Show that these are mathematically equivalent to your expression assuming an object moves in a complete circle (a distance of $2\pi r$ in a time T).

2. **Predict.** According to our understanding of centripetal acceleration and net force, explain what happens to the magnitude of the centripetal force if the 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 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.



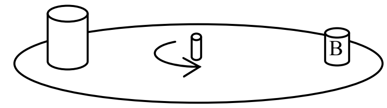
5. **Test.** Test your two predictions above. Note that keeping the same frequency is quite tricky! Were your predictions consistent with the observations?

SPH4U: Thinking About Circular Motion

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

A: Testing Our Understanding of Circular Motion

Two objects of mass 100 g and 200 g that have identical bottom surfaces are placed on a rotating platform that can turn with increasing speed. The two masses are placed at equal distances from the centre and have equal speeds at each moment in time.



1. **Predict.** Complete the chart below. The coefficient of static friction is μ_s.

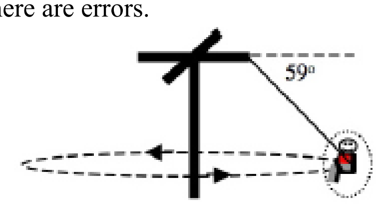
FBD	y-component of 2nd law	x-component of 2nd law	**Prediction**: Which mass will fly off first, or do they fly off at the same time?
Object A			
Object B			

2. **Test.** Was your prediction consistent with the outcome of the experiment? Explain. What might have caused any discrepancies? (Hint: Think of the assumptions you made.)

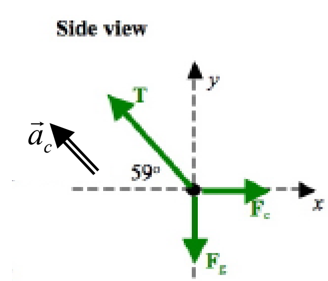
B: Evaluate the Problem

Identify any errors in the solution to the following problem. Provide a corrected solution if there are errors.

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 that makes a 59^o angle with the horizontal. Determine the tension in the cable.



Proposed Solution: The situation is pictured above. We simplify by assuming that Samuel, the system, is a particle. A FBD for Samuel is shown at the right along with the acceleration direction.

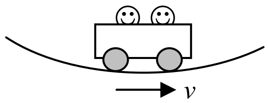
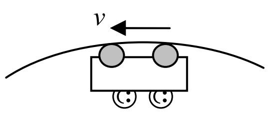
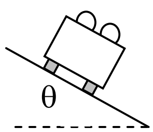
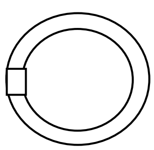


$$F_c = m(v^2/r)$$
$$= (80\text{ kg})(6.0\text{ m/s})^2/(6.0\text{ m})$$
$$= 480\text{ N}$$

The tension is 480 N.

C: Representations of Circular Motion

Complete the chart for situations #1-3. For #4 and 5, you must come up with a possible situation that agrees with the equation. Then complete the chart and write a description as if it were a textbook problem – be creative!

Words and Sketch	Direction of a_c (vector subtraction technique)	FBD	Newton's 2nd Law
(1) A roller coaster car moves along a frictionless circular dip in the track.  			
(2) The roller coaster moves past the top of a frictionless loop-the-loop.  			
(3) The rollercoaster travels around a banked corner on a frictionless track. At this moment it is travelling directly **out of the page**.  	*Hint*: Draw from a top view	*Hint*: Draw from a head-on view. There are no forces parallel to the incline	
(4)			900 N – (50 kg)(9.8 N/kg) = (50 kg)v^2 / (12 m)
(5)			200 N + (50 kg)(9.8 N/kg) = (50 kg)v^2 / (12 m)

SPH4U: Experimenting with Circular Motion

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

A: Experimental Ideas

Your task is to design a method to determine the magnitude of the net force exerted on the mass of a **conical pendulum** as the mass moves at a constant speed in a circle of a chosen radius. *Hint*: for more accuracy, use a circle with a large radius. You may use any of our classroom equipment.

1. (10 minutes) On your whiteboard, quickly outline an experiment that would allow you to measure the net force experienced by a conical pendulum. For ideas on what to consider, look at the list of headings in part B below.

2. Present to the class your experimental proposal.

B: Experimental Design

1. Based on ideas from the presentations, write a careful description of the method you will use to determine the net force. Draw a labeled sketch.

Method & Sketch

2. Draw a FBD

3. Write the physical quantities you will measure and the physical quantities you will calculate.

measured:

calculated:

4. Write the mathematical procedure you will use to determine the net force.

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

5. List additional assumptions.

6. List sources of experimental uncertainty and how to minimize them.

7. Perform the experiments and compare the two results. Discuss how assumptions and experimental uncertainties contribute to the discrepancy between the outcomes of the two experiments.

SPH4U: Universal Gravitation

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

Good old Sir Isaac Newton determined the relationship between the force of gravity, mass (m) and the separation between the centres of the two objects (r):

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

where $G = 6.67 \times 10^{-11}$ Nm^2/kg^2. Your friend, who is now an astronaut (m_A = 100 kg), is currently standing on the Earth (m_E = 5.98×10^{24} kg, r_E = 6.38 x 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 a FD for your friend and Earth.

2. **Calculate.** Use the equation for universal gravitation to find an algebraic expression for the ratio of force per unit of mass for the astronaut. Substitute the appropriate values into your expression and evaluate it. Explain the significance of this result.

Sketch	Astronaut FD	Earth FD

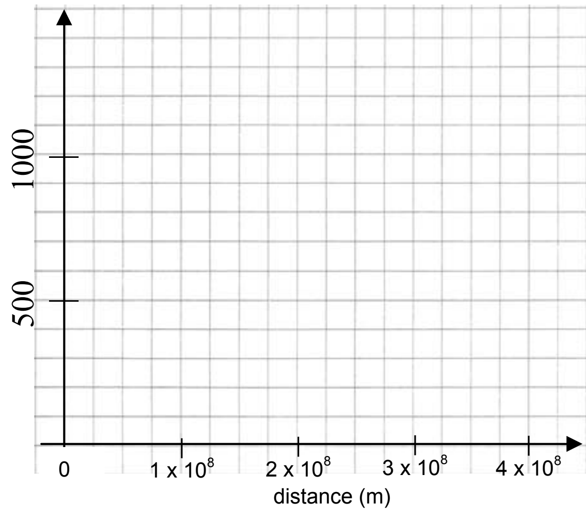
3. **Reason.** In your FDs you identified two forces of gravity. Compare the size and direction of these two forces.

4. **Reason.** Isaac says: "I understand from my laws 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.

5. **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?

6. **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 (0.06×10^8 m)	
Space Shuttle Orbit	6.39×10^6 m (0.06×10^8 m)	
Geosynchronous Orbit	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	
Mars' Orbit	7.9×10^{10} m	



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

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

9. **Reason.** 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!

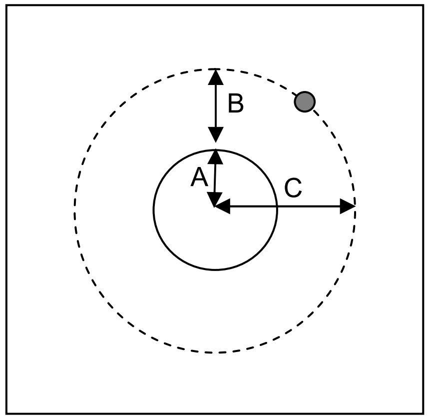
SPH4U: Orbits

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

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

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

1. Label the altitude (h), the radius of the circular orbit (r), the radius of Earth (r_E), matching them with the letters A, B, and C.



2. Which quantity, A, B, or C, does r in the expression for universal gravitation represent? Explain.

$$F_g = \frac{Gm_1 m_2}{r^2}$$

3. Which quantity, A, B, or C, does r in the expression for the centripetal acceleration represent? Explain.

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

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

FD

5. Use Newton's 2nd Law, 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.)

This result is known as Kepler's law, names after the brilliant mathematician who spent 25 years working out this result. How long did it take you?

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

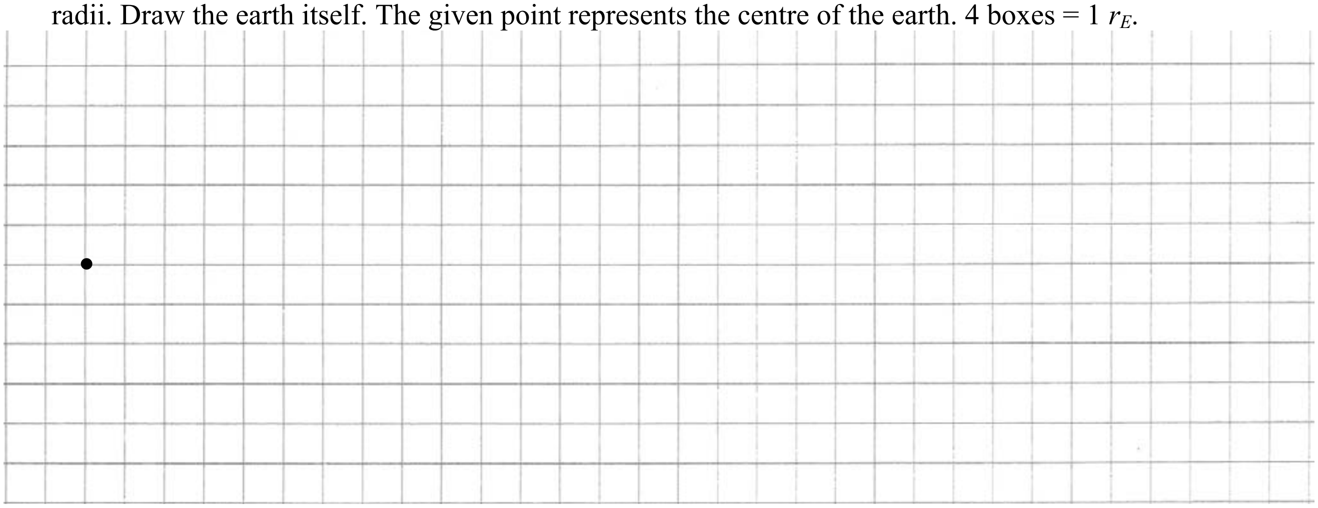
Location	Altitude	r (m)	T (s)
Space Shuttle Orbit	600 km		
Geostationary Orbit (satellite stationary above Earth's surface)			24 h =
Moon's Orbit			27 d =

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

7. Albert says, “I understand that there still is gravity out in space, sometime 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. 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. 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.

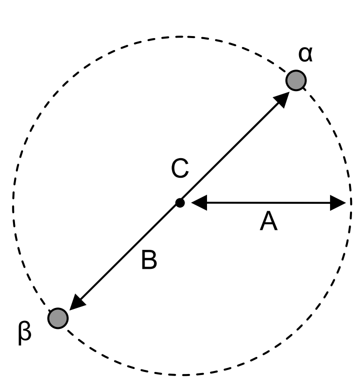


10. Using this scale, where would the Moon be located? **Carefully** find this position and **show your teacher**.

Consider a binary star system (*YM alpha* and *YM beta*) consisting of two equally massive stars which orbit one another.

11. How do you decide which star will orbit around which? Explain.

12. 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 A (radius) or B (diameter). C is the common centre around which both stars orbit.



13. 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

This tutorial introduces *momentum conservation*. Equally important, using momentum as an example, this tutorial explores the extent to which formulas relate to common sense.

A: What's Your View?

1. (*Work individually*) Which of the following best expresses your view about the relationship between physics formulas and common sense? (You can choose more than one.)
   i. Many physics *concepts* make a lot of sense and connect to everyday experience; but *formulas* are more of a problem-solving tool than a sense-making tool.
   ii. It really depends on the formula. Some of them make sense, but you shouldn't expect them to make sense as a general rule.
   iii. In general, physics formulas express some kind of common-sense ideas.

2. (*Work together)* Compare your answers with the rest of your group. If there was disagreement, have a debate—not to convince each other, but to understand each others' views. If someone makes a good point that disagrees with what you initially thought, summarize that point here.

B: Figuring Out the Formula for Oomph!

An important physical quantity, the name of which we'll give later, corresponds to the intuitive idea of *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. *If you already know the formula from a previous class, please "play along" and don't give it away.* We've structured this tutorial so that you'll learn something even if you already know the formula. We know some of you don't like mucking around with intuitions, but trust us, in this tutorial it'll lead somewhere quickly, and you'll end up practicing some physics.

1. **Reason.** A small pebble and a larger 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 rock's oomph compare to the pebble's oomph? Is it twice as big? Half as big? Three times as big?

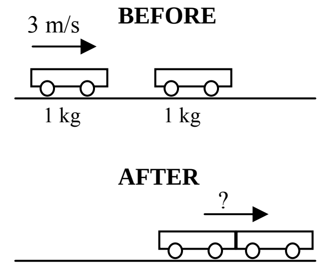
2. **Reason.** Picture two identical bowling balls, one of which is rolling faster than the other.
   (a) Which ball, the faster or slower one, has more oomph? Why?

   (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, figure out a formula for momentum (oomph) in terms of mass and velocity. Explain how the formula expresses your intuitions from parts A and B above. (For nutty historical reasons, physicists use the letter p for momentum.).

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

C: Testing our Momentous Intuitions



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 your ideas hold true for collisions. Cart A (1 kg) is rolling with negligible friction at 3 m/s and collides with and sticks to cart B (identical to cart A). So, after colliding, the carts roll together as a single unit.

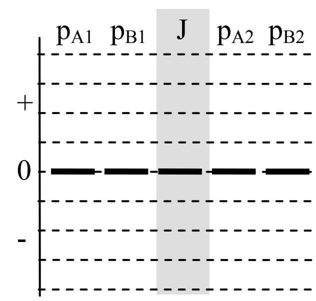
1. **Predict.** Using your intuitions, guess the post-collision speed of the two carts. Briefly explain your reasoning.

2. **Explain.** According to the intuitive guess you just made, is the overall momentum of the two-cart system after the collision greater than, less than, or equal to the overall momentum before the collision? Work this out using the momentum formula you figured out above and plugging in the relevant numbers.

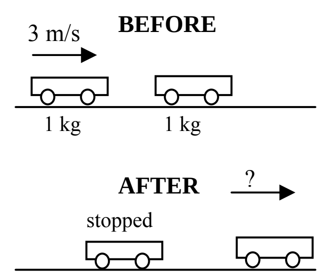
3. **Test and Observe.** Use the carts and dynamics track to test your prediction. Roughly speaking do your observations agree with your prediction? Did the first cart gain or lose momentum? What about the second cart? What about the system of two carts, did it gain or lose momentum?

To help represent the momenta of a system during a process like a collision we can construct a *momentum-impulse 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 total 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 of the system was zero.

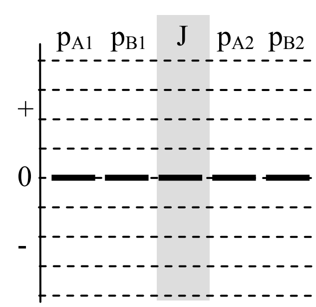


Here is another situation to consider: In a similar experiment, cart A collides with cart B magnetically. The two carts don't actually touch – the magnets act like a perfect spring between the two carts. After the collision cart A is at rest.



5. **Predict.** Again using intuitions, guess the post-collision speed of cart B.

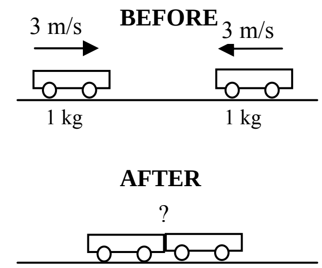
6. **Explain.** According to the intuitive guess you just made, is the overall momentum of the two-cart system after the collision greater than, less than, or equal to the overall momentum before the collision?



7. **Test and Explain.** Use the carts and dynamics track to test your prediction. Roughly speaking do your observations agree with your prediction? Did the first cart gain or lose momentum? What about the second cart? What about the system of two carts, did it gain or lose momentum? Complete the momentum-impulse bar chart.

8. **Summarize.** Based on your work above, state a general rule about how the total momentum of a system changes during a collision.

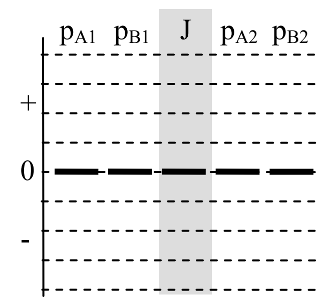
Here is one last situation to try out. The two carts are initially moving at 3 m/s in opposite directions collide and stick using Velcro.



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

10. **Reason.** In all cart collisions explored above, momentum was conserved; it was the same before and after the collision. Because conserved quantities are useful in problem-solving, it would be cool if we could define momentum in such a way that it's always conserved in collisions (between objects that are free to move). Is there some way to modify or clarify the momentum formula you figured previously so that momentum is conserved in the head-on collision between the two carts? Explain. (Hint: Maybe oomph "cares" about direction.)

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



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

D: The Conservation of Momentum

Conservation of momentum is a fundamental physical law. Among other things, it says that when two objects collide, the total momentum of the system immediately after the collision equals the total momentum of the system immediately before the collision:

$$\text{Conservation of momentum:} \quad m_A\vec{v}_{A1} + m_B\vec{v}_{B1} = m_A\vec{v}_{A2} + m_B\vec{v}_{B2}$$

Since $\vec{p} = m\vec{v}$, and since velocity "cares" about direction, so does momentum. So, a negative oomph (momentum) can partially or fully cancel a positive oomph, as the Velcro™ carts demonstrated.

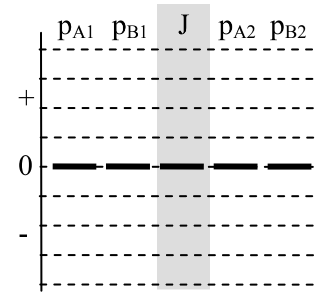
Problem. Let's practice using momentum conservation. On a safety test course, a 1000 kg car heading north at 5 m/s collides head-on with an 800 kg car heading south at 4 m/s. At these low speeds, the new high-tech bumpers prevent the cars from crumpling; they bounce off each other. After the bounce, the 1000 kg car is heading northward at 1 m/s. We're going to ask you for the post-collision speed and direction of motion of the other car.

1. **Represent.** A good, first step in any problem (one that will help you avoid mistakes) is sketching the initial and final states of the process. Do this! Label with symbols and values all of the known information. Identify the system and the unknown quantity.

2. **Predict.** Without doing calculations, "guess" the final direction of motion of the lighter car. Briefly explain your reasoning.

3. **Reason.** Are there any important interactions between the system objects and the external environment? Explain.

4. **Represent.** Complete a momentum-energy bar chart for the process.



5. **Calculate**. Now calculate the lighter car's speed and direction of motion after the collision. Make sure the equation is consistent with the bar chart.

6. **Evaluate.** Is your final answer reasonable (size, magnitude and direction)? Was your prediction right?

E: Thinking About Equations

Two students, after listening to one of their physics teacher's sermons about sense-making, are arguing about the conservation of momentum equation from the previous page (in the gray box).

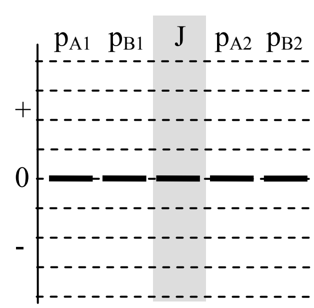
FRANK: I don't think the equation expresses common sense, because if it did, then we could have used common sense directly—instead of the equation—to solve the problem about the colliding cars. But we really needed the equation there to get the exact numbers.

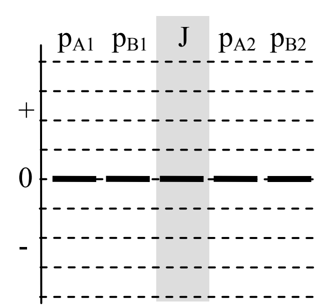
ERNEST: Sure we needed the equation. But the equation kind of expresses the common-sense idea that oomph stays the same in a collision. The whole point of expressing common-sense ideas in equations is to get something more generally useable, something we can use when common sense alone can't deal with the situation.

FRANK: You're admitting that the equation goes beyond common sense, because we can use it when common sense alone wouldn't get us anywhere. So, at least in those cases, the equation doesn't express common sense!

1. **Reason.** In what ways do you agree or disagree with Frank? With Ernest? What's your stance on this issue?

2. **Reason.** Some of you are probably wondering about impulse. We didn't see any examples where there was an impulse. Try this: complete a momentum-impulse bar chart for the system of cart A and for the system of cart B in the first collision example. Explain what each chart tells us about the impulse experienced by the individual carts.





SPH4U: Types of Collisions

Recorder: ________________
Manager: ________________
Speaker: ________________
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A collision, or in general, any process may roughly fall in to three categories based on the system's kinetic energy ($E_k = ½mv^2$). If the system loses kinetic energy due to the process, the process is called *inelastic*. If the system maintains its kinetic energy, the process is called *elastic*. And if the system gains kinetic energy, the process is called *superelastic*. Our goal today is to identify collisions that fall in to these three categories.

In our investigation, you will 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 judgements based on that.

A: The "Sticky" Collision

1. **Observe.** Play around with collisions where the carts stick due to Velcro. The goal is to find a sample collision that helps us to easily decide whether the sticky collision is *elastic*, *inelastic*, or *superelastic*. Hint: if the system is losing kinetic energy, overall, everything is kind of going slower.

2. **Represent and Reason.** Sketch the before and after situations. Estimate the speeds involved (for example, v_{A1} = 1 unit). Complete a momentum-impulse bar chart and a new kinetic energy bar chart. Does the system gain or lose kinetic energy? Decide what type of collision it is.

Situation: Sticky **Type of Collision**:

Initial State	Final State	Momentum-Impulse Bar Chart	Energy Bar Chart
		p_{A1} p_{B1} J p_{A2} p_{B2} (+, 0, -)	E_{kA1} E_{kB1} ΔE_k E_{kA2} E_{kB2} (+, 0, -)

Energy calculation:

B: The "Bouncy" Collision

1. **Observe.** Play around with collisions where the carts collide magnetically. The goal is to find a sample collision that helps us to easily decide whether the bouncy collision is *elastic*, *inelastic*, or *superelastic*.

2. **Represent and Reason.** Sketch the before and after situations. Estimate the speeds involved (for example, v_{A1} = 1 unit). Complete a momentum-impulse bar chart and a new kinetic energy bar chart. Does the system gain or lose kinetic energy? Decide what type of collision it is.

Situation: Bouncy **Type of Collision**:

Initial State	Final State	Momentum-Impulse Bar Chart	Energy Bar Chart
		p_{A1} p_{B1} J p_{A2} p_{B2} (+, 0, -)	E_{kA1} E_{kB1} ΔE_k E_{kA2} E_{kB2} (+, 0, -)

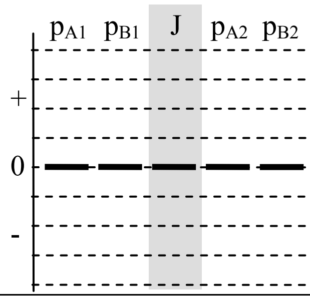
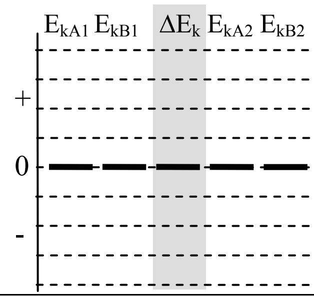
Energy calculation:

C: The "Thunk"Collision

1. **Observe.** Play around with collisions where the carts collide by hitting (neither magnetically nor with Velcro). The goal is to find a sample collision that helps us to easily decide whether the "thunk" collision is *elastic*, *inelastic*, or *superelastic*.

2. **Represent and Reason.** Sketch the before and after situations. Estimate the speeds involved (for example, v_{A1} = 1 unit). Complete a momentum-impulse bar chart and a new kinetic energy bar chart. Does the system gain or lose kinetic energy? Decide what type of collision it is.

Situation: "Thunk" **Type of Collision**:

Initial State	Final State	Momentum-Impulse Bar Chart	Energy Bar Chart
			

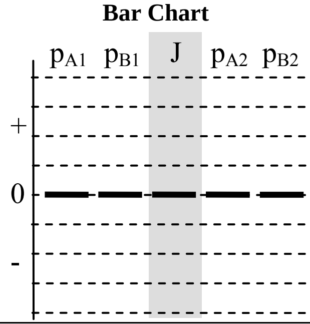
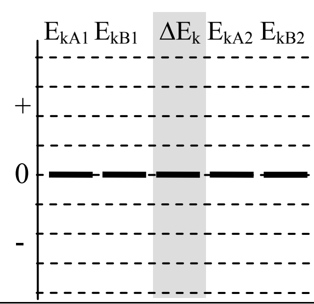
Energy calculation:

D: The Explosion

1. **Observe.** Play around with collisions where the carts explode! (load the springs and launch them – get ready to catch!) The goal is to find a sample collision that helps us to easily decide whether an explosion is *elastic*, *inelastic*, or *superelastic* process.

2. **Represent and Reason.** Sketch the before and after situations. Estimate the speeds involved (for example, v_{A1} = 1 unit). Complete a momentum-impulse bar chart and a new kinetic energy bar chart. Does the system gain or lose kinetic energy? Decide what type of collision it is.

Situation: Explosion **Type of Collision**:

Initial State	Final State	Momentum-Impulse Bar Chart	Energy Bar Chart
			

Energy calculation:

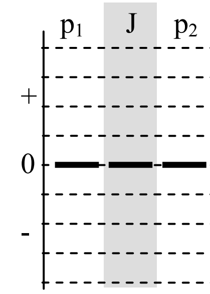
SPH4U: Momentum and Isolated Systems

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

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

A: The Slowing Block

A 1.0 kg block initially sliding at 1.5 m/s along a rough surface 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 objects and the external environment? How does this help to explain the loss of momentum?

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. $\Delta\vec{p}_{system} = \vec{J} = \vec{F}_{net}\Delta t$

3. **Represent**. Draw a force diagram for the block. Write an expression for the net force.

FD

4. **Predict.** 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!

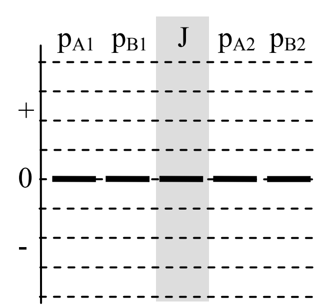
B: The Block on a Track

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 our two predictions. Describe how your observations help to confirm your predictions

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.



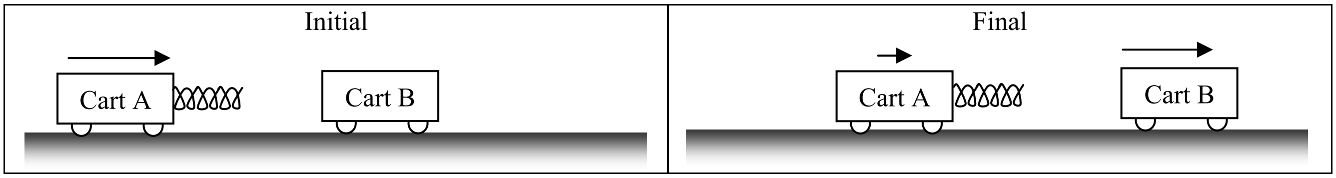
4. **Calculate.** What is the final velocity of the track? What type of collision is this?

5. **Reason.** Imagine the mass of the track was increased enormously to equal that of the earth. Describe what would be different.

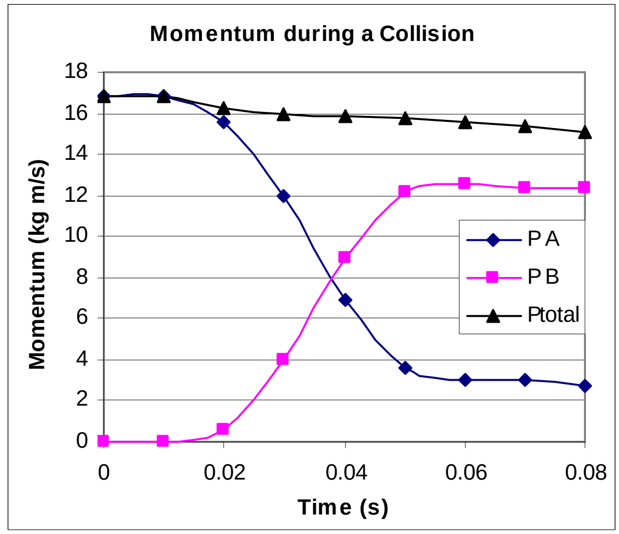
SPH4U: The Process of a Collision

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

Collisions often occur very quickly so we don't usually notice what is actually happening during a collision. In this example, cart A (3 kg) collided with a smaller cart B (2 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.



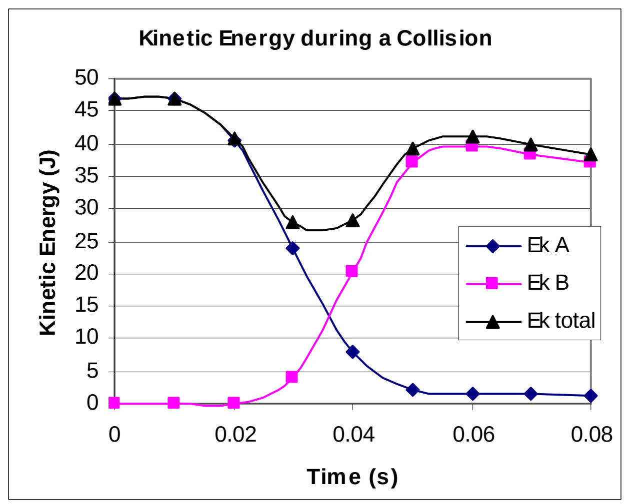
1. **Represent.** Draw a vertical line on each graph labelled "A" to indicate the moment in time when the collision begins and one labelled "C" to indicate when the collision ends. What is the duration of the collision?



2. **Reason.** What would we observe about the spring at moments "A" and "C"?

3. **Find a Pattern.** Compare the impulse and average net force experienced by each cart during the collision. Explain any patterns you observe.

	Cart A	Cart B
Impulse		
F_{net}		



A conserved quantity is one whose total for a system remains the same at *every* moment in time.

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 is been transferred to?

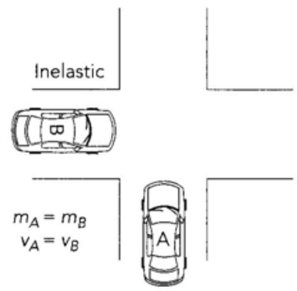
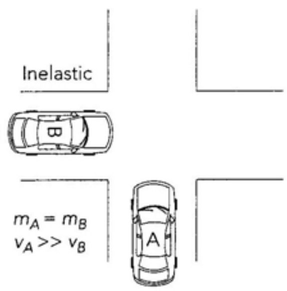
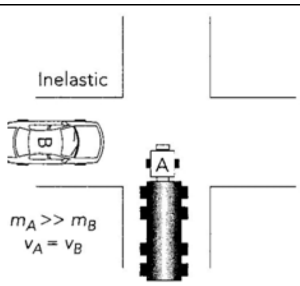
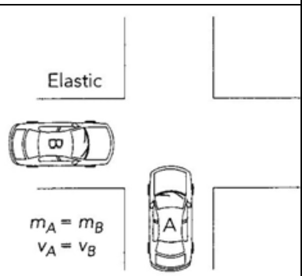
6. **Represent.** Draw a vertical line on each graph labelled "B" to indicate the moment in time when the spring was at its maximum compression. Approximately how much energy was stored in the spring at this moment?

SPH4U: Car Crash!

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

Two vehicles are racing into an intersection and crash! The collisions are so violent that the two vehicles stick together and move as one object after the collision.

1. **Predict.** Four different collisions are shown below along with mass and speed information (<< means much greater than). Sketch the momentum vectors for each vehicle before the collision. Use your intuition to predict the single momentum vector after the collision. Provide a very simple rationale for each prediction.

	Sketch	Momentum Before	Momentum After	Rationale	Observations
1					
2					
3					
4			* bouncy collision!		

2. **Test.** As a class, observe the simulations. Record your observations in your chart above. Did your observations confirm your predictions?

SPH4U: 2-D Momentum Problem Solving

A typical problem involving the conservation of momentum in 2-D is often challenging for students, usually due to lack of organization and careless mistakes.

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 30^o S]. Determine the velocity of Puck B after the collision.

sketch

1. Draw a sketch of the collision, including a prediction for the motion of puck A after the collision. Use symbols to label the important quantities.

2. Draw the coordinate system clearly showing the positive *x*- and *y*-directions.

3. Create a chart showing all the known velocities and their components. Use your sign convention at this step.

4. Write down an algebraic expression for the law of conservation of momentum in the *x*-direction. Solve this for the unknown.

   $m_A v_{A1x}$ +

5. Write down an algebraic expression for the law of conservation of momentum in the *y*-direction. Show explicitly the masses and velocity components. Solve this for the unknown.

   $m_A v_{A1y}$ +

6. If your final result is a vector, draw a vector triangle and construct the unknown quantity.

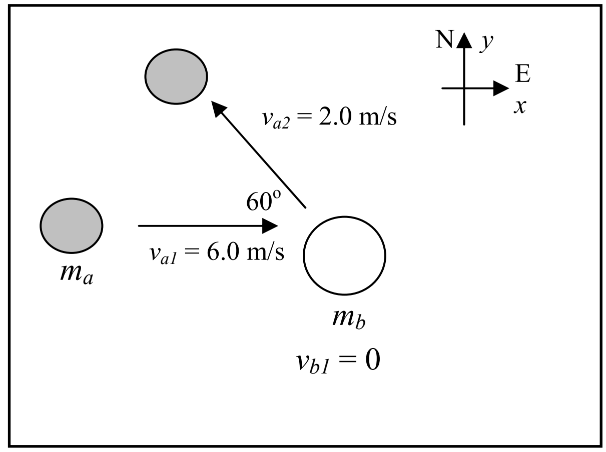
7. State your final answer in terms of the original problem.

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.

Consider a simple example where a small, fast moving mass (m_a = 2.0 kg) collides with a large stationary mass (m_b = 4.0 kg)



1. **Quickly** use you 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.

2. For simplicity we chose a coordinate system that lines up with v_a. Determine the x- and y-components of the momentum of each mass. Show your work and **be sure to use the given sign convention**.

p_{a1x} = p_{b1x} =

p_{a1y} = p_{b1y} =

p_{a2x} = p_{a2y} =

3. Complete the tables below. Calculate the total momentum in each direction before the collision. Use a scale of 1kgm/s = 1 square to draw the vector components of the momentum on the grid. The positive direction is to the right.

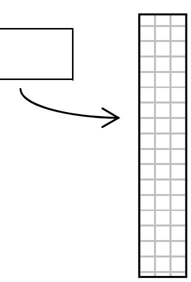
p_{a1x}			
p_{b1x}			
p_{t1x}			

p_{a1y}	
p_{b1y}	
p_{t1y}	

4. Complete the table below for the momentum components after the collision.

p_{a2x}			

p_{a2y}	



5. Compare the vector $\vec{p}_{tx}$ with $\vec{p}\,'_{ax}$. Based on your drawings for these vectors, predict what the vector $\vec{p}\,'_{bx}$ will look like. Briefly explain your reasoning.

p_{t1x}			
p_{a2x}			
p_{b2x}			

The conservation of momentum in the x-direction tells us that: $p_{a1x} + p_{b1x} = p_{a2x} + p_{b2x}$

6. Use the conservation of momentum in the x-direction to solve for p_{b2x}.

7. Issac 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.

8. Albert says, "The momentum of mass b in the *x*-direction is greater than the initial momentum in the *x*-direction. I think this is a problem". Do you agree or disagree with Albert? Explain.

9. Compare the vector $\vec{p}_{t1y}$ with $\vec{p}_{a2y}$. Based on your drawings for these vectors, predict what the vector $\vec{p}_{b2y}$ will look like. Briefly explain your reasoning.

p_{t1y}	p_{a2y}	p_{b2y}

The conservation of momentum in the *y*-direction tells us that:

$$p_{a1y} + p_{b1y} = p_{a2y} + p_{b2y}$$

8. Use the conservation of momentum in the *y*-direction to solve for p_{b2y}.

10. Looking back at your work so far, why was it helpful to choose a coordinate system that lined up with v_{a1}?

11. Use the components $\vec{p}_{b2x}$ and $\vec{p}_{b2y}$ to draw $\vec{p}_{b2}$. Compare this with your prediction.

12. Calculate $|\vec{p}_{b2}|$ and θ. Use these to determine $\vec{p}_{b2}$.

13. Determine $\vec{v}_{b2}$.

14. Complete the tables below. Calculate the total momentum in each direction after the collision. Compare the totals after with the totals before.

p_{a2x}		
p_{b2x}		
p_{t2x}		

p_{t1x}		

p_{a2y}	p_{b2y}	p_{t2y}

p_{t1y}

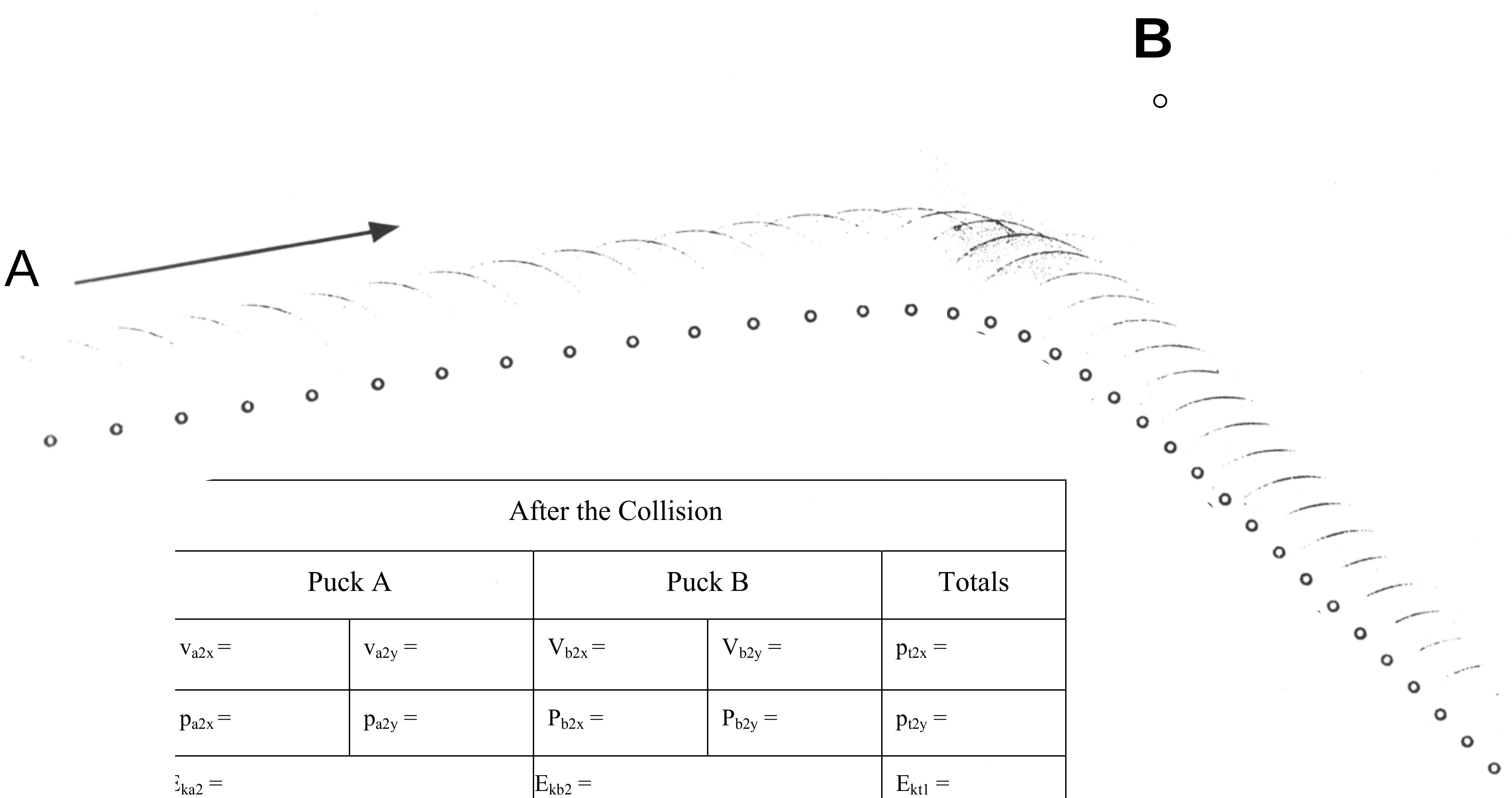
15. What does it mean to say, "Momentum is conserved in each direction"? Use the results from the previous question in your answer.

SPH4U: 2-D Collisions

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

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. The image is shown to scale. Show your results on the this page and your work on the following page.

Before the Collision				
Puck A		Puck B		Totals
v_{a1x} =	v_{a1y} =	V_{b1x} =	V_{b1y} =	p_{t1x} =
p_{a1x} =	p_{a1y} =	P_{b1x} =	P_{b1y} =	p_{t1y} =
E_{ka1} =		E_{kb1} =		E_{kt1} =



After the Collision				
Puck A		Puck B		Totals
v_{a2x} =	v_{a2y} =	V_{b2x} =	V_{b2y} =	p_{t2x} =
p_{a2x} =	p_{a2y} =	P_{b2x} =	P_{b2y} =	p_{t2y} =
E_{ka2} =		E_{kb2} =		E_{kt1} =

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. **Reason.** Isaac says, "Let's use units of cm/s with our calculations – 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. **Observe and Calculate.** Write an equation for the conservation of momentum in the *x*-direction where v_{b2x} is the unknown. Make the necessary measurements from the first page and record these in the chart. Solve the equation for v_{b2x}. Note: the equation will simplify. Explain why.

5. **Observe and Calculate.** Write an equation for the conservation of momentum in the *y*-direction where v_{b2y} is the unknown. Make the necessary measurements from the first page and record these in the chart. Solve the equation for v_{b2y}.

6. **Calculate and Test.** Determine the vector $\vec{v}_{b2}$. Draw the vector beginning at the circle under the "B".
   ** *Check this with your teacher!* **

7. **Reason.** Isaac says, "To calculate the kinetic energy of puck A after the collision we should make a separate calculation using v_{a2x} and v_{a2y} and add the results together." Emmy says, "I think we should just use v_{a2} in $\frac{1}{2}mv^2$ and make just one calculation." Who do you agree with? Explain.

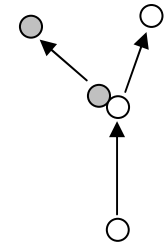
8. **Calculate and Reason.** Use kinetic energy calculations to help explain what type of collision this is.

SPH4U: Experimenting with a 2-D Collision

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

A: Experimental Ideas

Your task is to verify whether momentum is conserved during a Y-shaped two-dimensional collision between two hover pucks. You will need to devise a technique to determine the 2-D velocities of the pucks before and after the collision. You are welcome to use the standard classroom equipment.



1. (15 minutes) On your whiteboard, quickly outline an experiment that would allow you to measure the velocities of the two pucks before and after the collision. For ideas on what to consider, look at the list of headings in part B below.

2. Present to the class your experimental proposal. Don't worry if it's not complete, the purpose is to share ideas and find the best ones for your experiment.

B: Experimental Design

1. Based on ideas from the presentations, write a point-form description of the method you will use to determine the velocities. Draw a labeled sketch.

Method & Sketch

2. Write the physical quantities you will measure and the physical quantities you will calculate.

measured:

calculated:

3. Write the mathematical procedure you will use to verify whether momentum was conserved during the collision.

4. List any assumptions or simplifications.

5. List sources of experimental uncertainty and how to minimize them.

6. Perform the experiment and complete your verification. Use your estimated errors to comment on the success of your experiment.

SPH4U: Working the Angles

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

Energy can be transferred into or out of a system due to the effects of an external force acting on the system – we call this a flow of energy. Let's track this flow and decide what happens to the system. You will need a spring scale (5 N or 10 N), a dynamics cart, a smooth surface, lots of mass (2 or 3 kg), and a protractor.

1. **Observe and Describe.** Add lots of mass to your dynamics cart and practice pulling it approximately 0.5 m with a small, constant rate of acceleration. Repeat until you are good at it! Is any energy being transferred in this situation? Explain.

An energy flow diagram consists of a circle that represents the boundary of the system. Listed inside that circle are the system objects. Listed outside the circle are objects from the environment that interact with the system. Arrows crossing in or out of the system show the flow of energy due to an interaction with an external object.

2. **Represent.** Draw an energy flow diagram for this system.

Energy Flow Diagram

The amount of energy transferred due to a force is called the *work* and is related to the external force acting on the system and the displacement of the system. When a single, unbalanced force does work on a system, the kinetic energy of the system will change.

A provisional definition of work based on the ideas above is: $W = F \cdot \Delta d$

1. **Observe and Test.** Let's test our provisional definition of work by making measurements with the cart. Pull the cart just as described in question #1. Be sure the hold the spring scale *horizontally*. Record the magnitude of force and the distance traveled in the chart below. Calculate the work done on the cart.

F_1 =	Δd_1 =	W_1=

2. **Observe and Test.** Repeat the measurement, except pull on the cart with an angle 30° above the horizontal. Try to give the cart the same acceleration as before! Record the magnitude of force and the distance traveled in the chart below. Calculate the work done on the cart.

F_2 =	Δd_2 =	W_2=

3. **Evaluate.** Judging by your observations, how do the kinetic energies of the cart compare in each situation? Judging based on your calculations, how do amounts of work compare? Is our provisional definition of work valid? Explain.

4. **Reason.** We must decide how to modify our definition of work. For a given force, at what angle θ between the force and the direction of motion would the work be a maximum? A minimum? (in absolute values!) Sketch these situations. At what angle is the cosine function a maximum? A minimum? (in absolute values!)

5. **Reason.** Modify the simplistic expression, $W = F\Delta d$, to incorporate what you have learned about angles. Draw a diagram showing the two important vectors, displacement and force, and the angle θ.

Adapted from: Laws, P. *Workshop Physics Activity Guide. Module II*. John Wiley, 2004

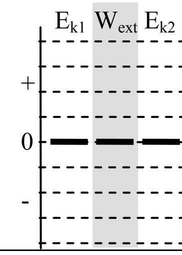
SPH4U: Work and Kinetic Energy

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

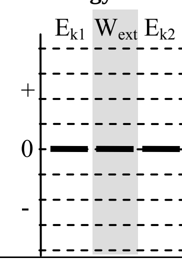
A: Two Types of Work

1. **Represent.** A cart is initially moving to the left on a frictionless, horizontal table. Your hand exerts a constant, horizontal force to the left on the cart. Record your answers to the following questions in the chart below.
   (a) Draw a sketch of this situation. Draw arrows to show the displacement of the cart and the force you exert.
   (b) Is the cart *speeding up, slowing down,* or *moving with a constant speed*? Complete a motion map for the cart and describe its motion.
   (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? Record this under "Type of Work".
   (e) Complete the work-energy bar chart for the system of the cart.

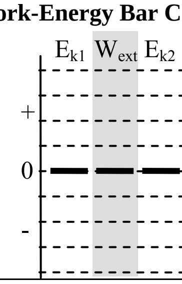
A work-energy bar chart represents the energies present in a system at two moments in time. If the total energy of the system changes, we include the work done by external forces. The heights of the bars in the graph do not need to be exact – we draw this chart before we make any calculations. What is important is that bars illustrate the correct ideas.

Type of Work	Displacement of cart	Motion Map	Energy Flow Diagram	Work-Energy Bar Chart
				
Sketch	**Force acting on cart**	**Description of Motion**		

2. **Represent.** The cart is initially moving to the left on a frictionless, horizontal table. Your hand exerts a constant, horizontal force to the right on the cart (it continues moving left). Complete the chart.

Type of Work	Displacement of cart	Motion Map	Energy Flow Diagram	Work-Energy Bar Chart
				
Sketch	**Force acting on cart**	**Description of Motion**		

3. **Represent.** The cart is initially moving to the left on a frictionless, horizontal table. Your hand exerts a constant, **vertical** force downwards on the cart (it continues moving left). Complete the chart.

Type of Work	Displacement of cart	Motion Map	Energy Flow Diagram	Work-Energy Bar Chart
				
Sketch	**Force acting on cart**	**Description of Motion**		

4. **Reason**. Does the result of the work equation depend on your choice of coordinate system? 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. Initially the cart is moving to the right and is now speeding up.
   (a) Draw a sketch of this situation.
   (b) Draw a motion map for the cart.
   (c) Draw a complete force diagram for the system of the cart.
   (d) 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.
   (e) Draw an energy flow diagram clearly showing each interaction between the system and external objects where energy is transferred.

Sketch	**Motion Map**	**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 individual works 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 system that experiences a net force will accelerate and gain or lose kinetic energy. This idea is called the *net work - kinetic energy theorem,* $W_{net} = \Delta E_k$

2. **Reason**. Is the net work on the system above positive, negative or zero? Write your explanation in the chart above.

3. **Represent**. Two hands continue to push on opposite ends of the cart, but with different magnitudes than before. For each situation, complete the chart below like in question #1 above.

Description	**Motion Map**	**Force Diagram**	**Energy Flow Diagram**	**Net Work**
The cart is moving to the left and is slowing down.				

Description	**Motion Map**	**Force Diagram**	**Energy Flow Diagram**	**Net Work**
The cart is moving to the left with a constant speed.				

4. **Summarize.** What is the significance of positive, negative and zero net work?

Adapted from McDermott, L. *Tutorials in Introductory Physics.* Prentice Hall, 2002

SPH4U: Energy and Frames of Reference

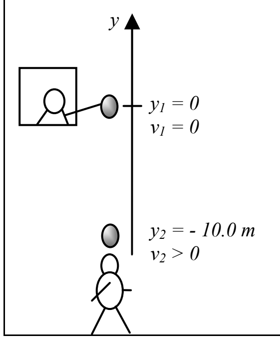
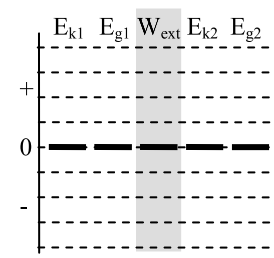
Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

Gravitational potential energy is a special kind of energy that depends on an object's vertical position. But what happens if to different observers choose a different vertical origin for their measurements? Let's find out!

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 you 10 meters above her. You release the water balloon. We will analyze what happens next from the frame of reference of you and also of your friend.

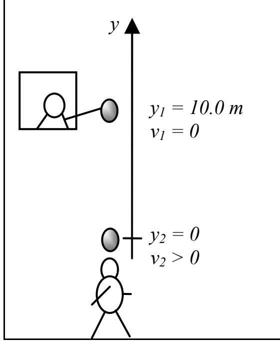
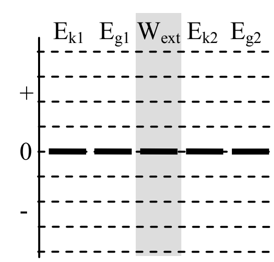
A: Your Frame

You set your vertical origin at your hand. Calculate the energies involved. Use a kinematics calculation to help find v_2. Add up the total energies at each moment. Complete the work-energy bar chart for the earth-balloon system.

Sketch	Potential Energy	Kinetic Energy	Total Energy	Work-Energy Bar Chart
	$E_{g1} =$ $E_{g2} =$	$E_{k1} =$ $E_{k2} =$	$E_{T1} =$ $E_{T2} =$	

B: Your Friend's Frame

In your friend's frame we set the vertical origin at her head. Calculate the energies involved. Use a kinematics calculation to help find v_2. Add up the total energies at each moment. Complete the work-energy bar chart.

Sketch	Potential 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. **Reason.** What does each observer conclude about the total energy of the system? Explain.

2. **Reason.** The two observers do not agree on the total energies, but this is not a problem. What is important in physics are energy *changes*. What does each observer conclude about the amount of energy that transfers from one type to another within the system? Explain.

Adapted from: Laws, P. *Workshop Physics Activity Guide. Module II.* John Wiley, 2004

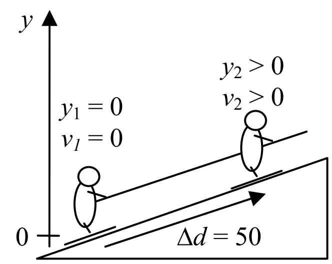
SPH4U: Transfers of Energy

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 systems and which can be used to predict whether some event may occur. 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

The Tow Cable. You decide to build a ski rope tow for the hill behind our school. A cable will pull a 100-kg skier up a hill inclined 20° above the horizontal. The skier starts at rest at the bottom and is to move at 6.0 m/s at the top. The hill is 50 m long, and a 150-N friction force opposes the skier's motion. You want to buy a motor that provides the average cable tension needed to pull the skier. How large is the tension?



1. **Reason.** What objects interact with the skier and what is the type of each interaction?

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 choose **any** system and, if we do our work properly, we should always agree on the final answer. Once the system is chosen, we can describe any interactions as **internal** or **external**.

2. **Reason.** In this example, we will choose the skier + earth (including the hill) as the system. Which of the interactions you mentioned above are internal and which are external? Draw an energy flow diagram for this system.

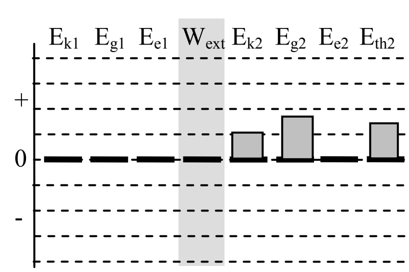
Energy Flow Diagram

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 is often due to the work done by an external force. The energy of the system and its changes may be expressed by a *work-energy equation*: $E_{T1} + W_{ext} = E_{T2}$. Internal interactions are usually described using energies (kinetic, potential and thermal) while external interactions are described as work done by forces. If we know an energy equation that corresponds to an interaction, it is convenient to choose our system such that it is an internal interaction.

3. **Reason.** Which forms of energy will be present in the system at moments 1 and 2, as shown in the diagram?

4. **Reason.** Which types of energy will change as a result of each interaction you have identified?

5. **Represent.** Complete the work-energy bar chart for the skier problem. The energies at moment 2 are provided. Explain how you complete it.



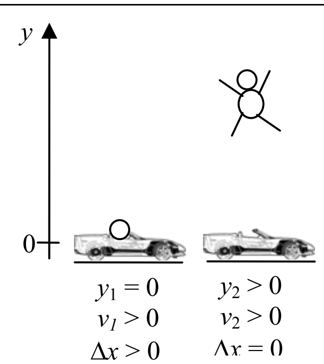
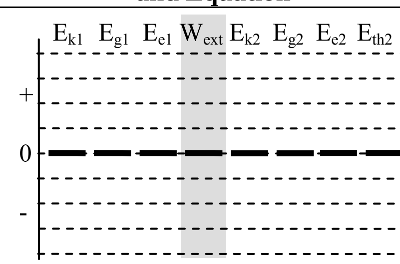
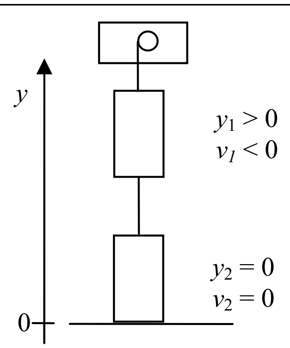
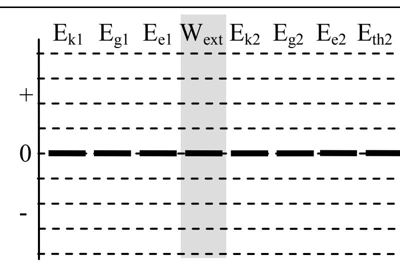
6. **Represent.** The bar chart helps you to write the work-energy equation for the system between the two moments in time. Do this using the same symbols as in the chart.

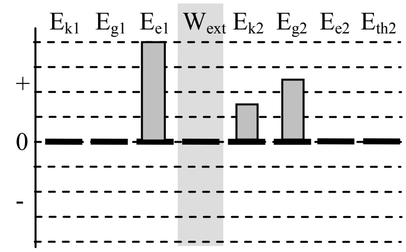
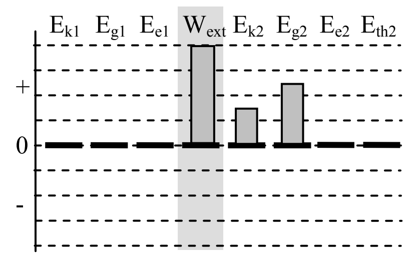
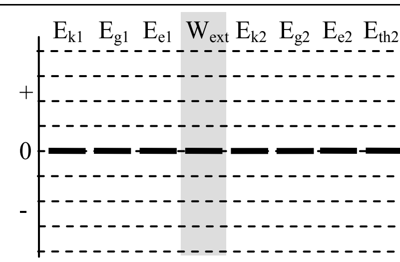
7. **Represent.** An internal force of friction can work to heat up the surfaces of the system objects, which means we need to keep track of thermal energy too. The amount of energy converted to heat due to the work done by friction is: $E_{th} = -W_{friction}$. Complete this expression using your understanding of work and sliding friction.

8. **Calculate.** Now complete your work-energy equation by algebraically substituting for each energy and work term. Solve for the force of tension. (Hint: the angle 20° is only used once in this equation – why? Hint: the equation does get a bit long – you may wish to calculate the individual energies first rather than doing all the algebra.)

B: Representations of Energy

1. **Represent.** Each row in the chart below gives multiple representations of one situation. Complete the missing parts for each row – come up with new and interesting situations where appropriate.

Word Description	Sketch of Initial and Final States	Work-Energy Bar Chart and Equation
(i) A stunt car is driving along and the spring-powered ejector seat is activated. 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: 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)		 System: Equation:
(iv)		 System: Equation:
(v)		 System: Equation: $\frac{1}{2}mv_1^2 + mgh = F_f h/\sin\theta$

2. Be prepared to present one of your created situations to the class.

A useful type of energy to track is the **total mechanical energy,** meaning sum of the kinetic and potential energies. When the total mechanical energy of a system is conserved, we may compare total energies *without having to consider the intermediate motion* or *work done by internal forces.* For example, if there is no friction, we don't need to know the shape of the hill a car glides along – not at all!

3. **Reason.** In which situations above was mechanical energy conserved? Explain.

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

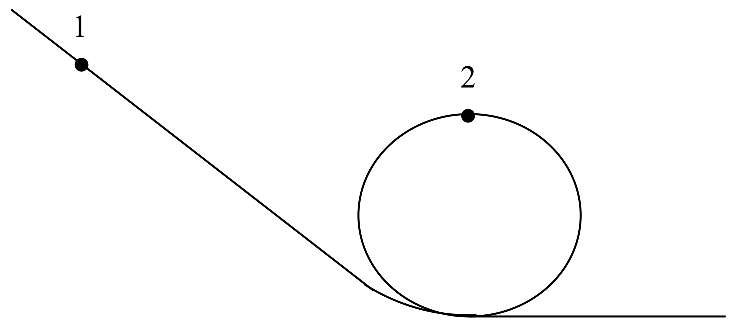
SPH4U: Rollercoasters and Energy!

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

Your challenge today is to determine the lowest starting position of a rollercoaster car such that when it is released, it can make it through a loop-the-loop! The real rollercoaster is modeled by the car and track at the front of the room. This is a very complicated situation, largely due to the friction that we must account for, and we will be making a number of simplifying assumptions to help us do this.

A: The Track

The model track is shown in the diagram to the right with two important moments in time indicated.



1. **Observe.** There are a number of key quantities which will be important in solving this problem. Take a few moments to decide what to measure and label the diagram above with the results.

2. **Reason.** Your teacher will give you a measured value for an average force of friction along the track. Why will we simplify our work by using an **average** value for the force of friction?

3. **Reason.** Are there any other simplifying assumptions we should make or have already made?

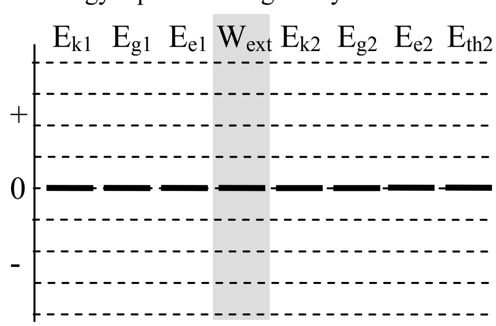
B: Energy Transfers

The rollercoaster car will be released from rest at moment 1 and needs to make it around the loop, successfully traversing the top at moment 2. As we begin to consider energy, we need to carefully define the system involved.

1. **Reason.** What objects interact with the car as it travels between moment 1 and 2? Based on this, define your system. Which forces experienced by the car will be internal and external?

2. **Predict.** How high should the starting height be compared with the radius of the loop *r*? Explain.

3. **Represent.** Construct a work-energy bar chart for this system at moments 1 and 2. Use the chart to help write a work-energy equation using the symbols in the bar chart.



Work-energy equation:

4. **Reason.** Is mechanical energy conserved between moments 1 and 2? Explain.

C: Solving the Problem

1. **Reason.** Circular motion is a key part of this problem. Explain how we can find the *minimum* speed of the car at moment 2 such that it makes it through the loop. Use appropriate diagrams and equations to find an algebraic expression for the speed at moment 2.

2. **Reason.** To find the thermal energy at moment two, it is helpful to divide up the car's trip between moments 1 and 2 into two sections: one along the incline and one up the circular loop. Write an expression for the thermal energy during each part of the trip.

3. **Calculate.** Which individual energies can we calculate right away? Find these values. Show your work in the chart below.

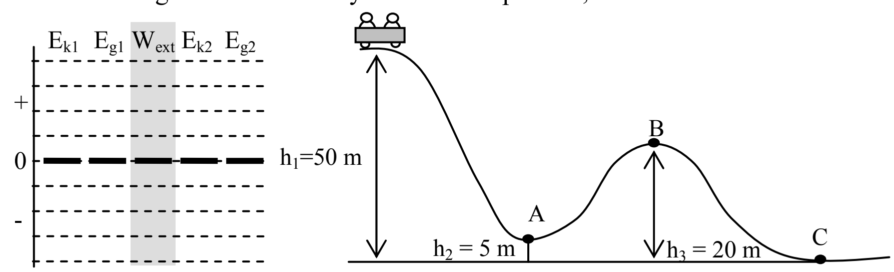
4. **Calculate.** Put all the pieces of the work-energy equation together and solve the problem.

5. **Reason.** Compare your result with an idealized no friction case. Based on this result, does your answer for the friction case seem reasonable?

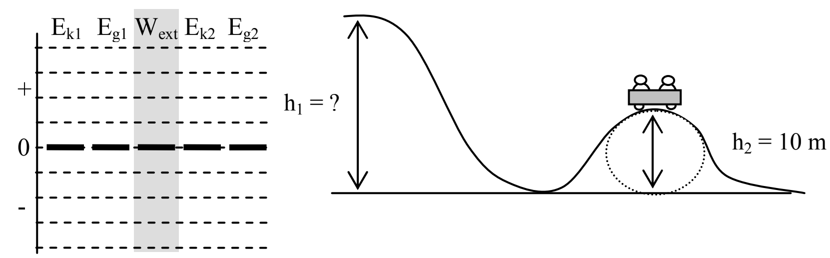
SPH4U: Amusement Park Physics

In all these problems, unless you are told otherwise, assume that the rollercoaster cars start from rest and that there is no friction. These roller coasters are the exciting old fashioned kind that are not fastened to the track. This means that they could actually fall off a loop-the-loop or a steep downwards hill! For each problem begin by completing a work-energy bar chart.

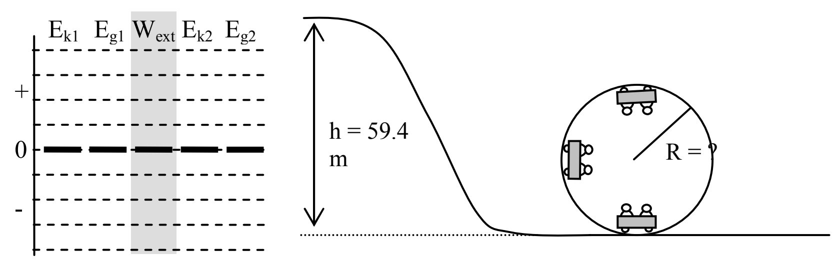
1. The diagram shows a design for the first two hills of a rollercoaster. A real rollercoaster will have friction acting on it. This force of friction would be quite complicated but we will make a very handy simplification. Assume that the force of friction is a constant value of 300 N, regardless of the occupants of the cars, the angle of incline of the track or the coaster's acceleration. The mass of the cars is 1000 kg. Find the velocity of the car at point B, where B is 150 m downtrack.



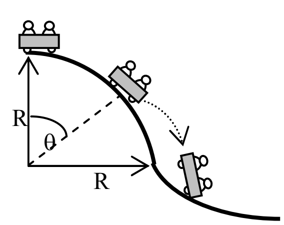
2. The diagram shows the first two hills of a rollercoaster. What is the maximum starting height, *h*, so that the rollercoaster does not leave the track at the top of the circular hill? Hint: It is not 10 m! and when the car is about to leave the track $Fn = 0$.



3. The diagram shows a circular loop-the-loop. The Magnum XL-200 is one of the world's fastest roller coasters with a starting drop of 59.4 m. Determine the maximum possible radius for the first loop such that the car does not fall from the track!



Super Challenging Bonus:
A rollercoaster designer had the swell idea of designing a death-defying circular first drop to a roller coaster, hoping that the cars would plunge almost straight down before the curve at the bottom. What they found, however, was that the cars would leave the track and go flying like a projectile. At what angle θ does the car fly off the track?



SPH4U: The Ballistics 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 ballistics 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 ballistics pendulum.

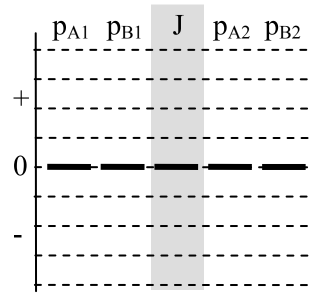
A: Understanding the Pendulum

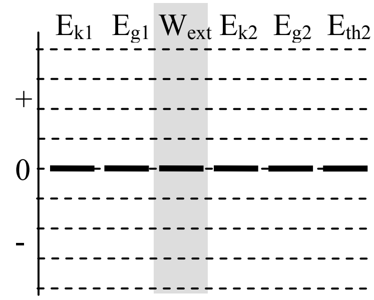
1. **Reason.** There are two important physical processes that take place when using a ballistics pendulum. What are they?

   Process A:

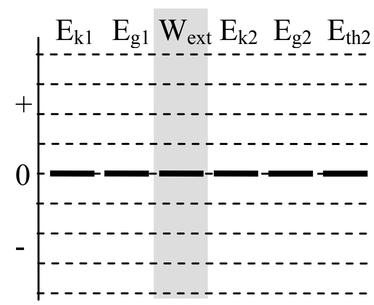
   Process B:

2. **Represent.** Use a momentum-impulse bar chart and a work-energy bar chart to explain what happens during the first process.





3. **Represent.** Use a work-energy bar chart to explain what happens during the second process.



B: Solving the Problem

1. **Represent.** Write down the equations for the two processes.

2. **Calculate**. Find the speed of your blob of play-doh.

3. **Evaluate.** Does your answer seem reasonable (size, units, direction)? Explain.

SPH4U: Spring Force and Energy

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

We would like to quantify the force and work needed to extend a spring as a function of its displacement from its unstretched position. Let's start by carefully measuring the force and work needed to stretch a brass spring. You will need:

- 1 metal spring, 1 spring scale (10 N), 1 C-clamp, 1 metre stick

We want to explore the relationship between the amount of force applied to the spring and the amount of stretch produced. You will use the C-clamp to hold one end of the spring in place and stretch the other end using the spring scale.

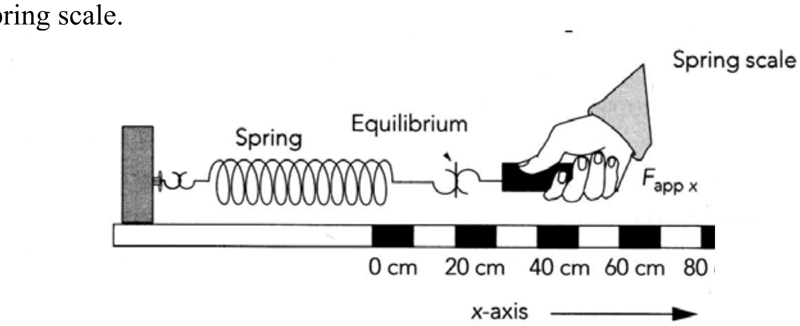


Fig. 10.14. Setup for measuring spring forces. The origin of the *x*-axis should be defined so the spring is in its equilibrium (unstretched) position at *x* = 0.00 m.

Part A: Force and Springs

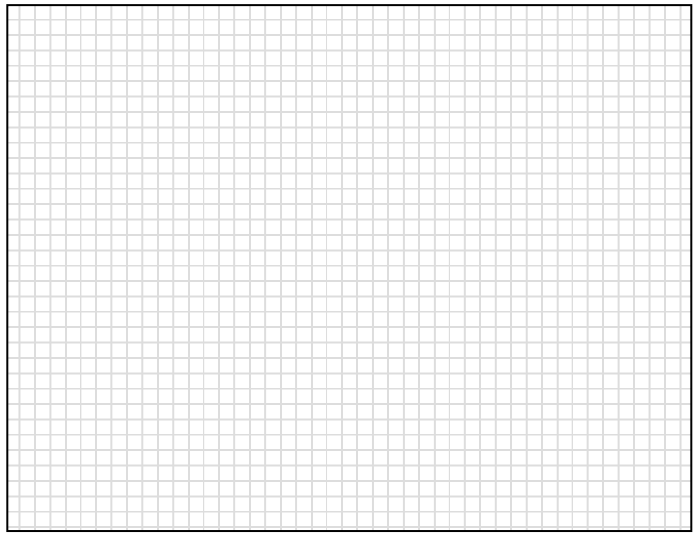
1. Before making any measurements, describe in an intuitive way (without numbers) how the stretch should depend on the amount of force applied. Provide a simple explanation to your younger brother for why you believe this.

2. Make five measurements and complete the applied force column of the data chart below. Don't fill in the shaded boxes!

Displacement from Equilibrium (m)	Force Applied (N)	Partial Displacement: $x_n - x_{n-1}$	Average Force during Partial Displacement (N)	Partial Work (J)
$x_0 = 0.00$				
$x_1 = 0.10$				
$x_2 = 0.20$				
$x_3 = 0.30$				
$x_4 = 0.40$				
$x_5 = 0.50$				
			Total Work (J)	

3. Plot a graph that shows how the force depends on the stretch. (Which axis should the force be on?)

4. Draw a line of best-fit and find the slope of the line. Use the symbol *k* to represent the slope of the line. What is the value of *k*? What are its units? **Note:** *k* is known as the spring constant.



5. What does a large or small spring constant tell us about the physical characteristics of a spring?

6. Write an equation describing the relationship between the force you applied to the spring, F_{app}, and the displacement, x, of the spring from its equilibrium position using the symbols F_{app}, x, and k. Explain what this equation tells us about the relationship between the force applied and the stretch.

7. According to Newton's 3rd law, the spring exerts a restoring force on the spring scale or on your hand that is equal and opposite to the applied force, so

   $F_{spring} =$

If a restoring force on an object is proportional to its displacement, it is known as a Hooke's Law force. This law is named after an erratic, contentious genius named Robert Hooke who was born in 1635.

Part B: Energy and Springs

1. We want to find the amount of work done as we stretch the spring. Two students discuss how to do the calculation. Alice says, "I think we should use the value of the force at the start of the displacement and multiply that by the stretch since the force is always smaller at the beginning." Bob says, "I think we should use the value of the force at the end of the displacement since it can become quite large, otherwise your result would be too small." Both are wrong. Why?

2. We used our spring scale to exert a force and stretch the spring, doing work. Describe the energy transformations that take place as you stretch the spring.

3. The chart for question **A.2** contains three columns that will help us calculate the work. Explain the meaning of the quantity in each column. After that, complete the chart.
   a) Partial displacement:

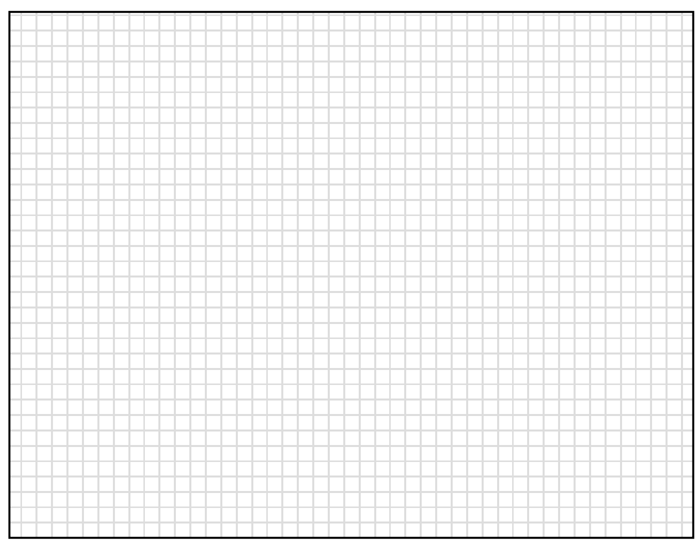
   b) Average force:

   c) Partial work:

2. Now we are ready to calculate the total work done to stretch a spring from its equilibrium position to each displacement. To do this, consider that the work to displace the spring to 0.20 m is equals the work to go from 0 to 0.10 m plus the work to go from 0.10 to 0.20 m. Complete the chart to the right and plot a graph of total work vs. displacement.

Displacement from equilibrium (m)	Total Work (J)
0	
0.10	
0.20	
0.30	
0.40	
0.50	

3. Calculate the work need to stretch the spring to a displacement of 0.40 m by computing the area under the F_{appx} vs. x graph you created earlier. Compare this with your result from #5.



4. Speculate on an equation that relates W and x. Hint: Consider how you computed the area to get the work. You may be guessing that this is indeed related to an integral!

SPH4U: Elastic Force and Energy

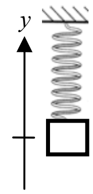
Recorder: ____________________
Manager: ____________________
Speaker: ____________________
0 1 2 3 4 5

A block is attached to the bottom of a spring which is hanging vertically. We lift it up and let it go. Let's try to understand what happens to the system's energy.

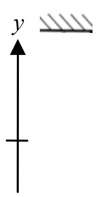
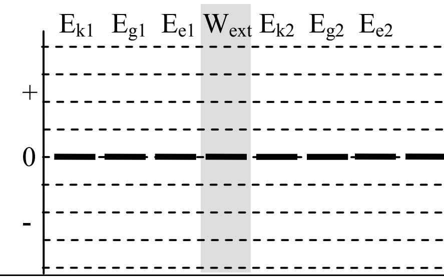
The block initially rests at its equilibrium position – it has not been disturbed. We choose the vertical origin such that the total energy of the system is zero.

1. **Represent.** At this moment in time (moment 1), draw a force diagram for the block

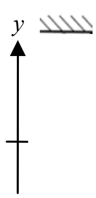
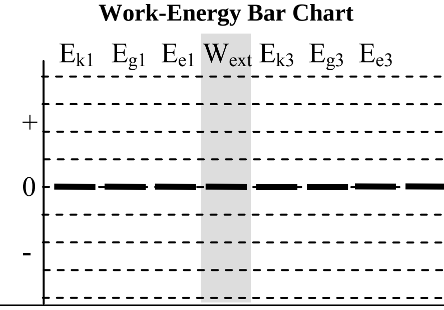
2. **Explain.** What does the term *equilibrium position* mean?

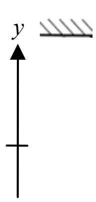
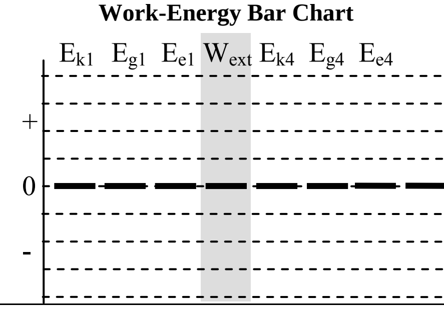
Moment 1	Force Diagram
 $y_1 = 0$ $v_1 = 0$ $\Delta x_1 = 0$	

3. **Reason.** For each moment in time described below do the following: Complete the sketch, draw a force diagram for the block, draw vectors for the block's velocity, acceleration and net force, and complete a work-energy bar chart for the block-spring-earth system.

Moment 2	Sketch	Force Diagram	Vectors	Work-Energy Bar Chart
You lift up the block and release it from its highest position. Moment 2 is just after it has been released.	 $y_2 =$ $v_2 =$ $\Delta x_2 =$			

4. **Reason.** Was the energy of the system conserved between moments 1 and 2? Explain.

Moment 3	Sketch	Force Diagram	Vectors	Work-Energy Bar Chart
The block passes by its equilibrium position.				

Moment 4	Sketch	Force Diagram	Vectors	Work-Energy Bar Chart
The block reaches its lowest position.				

5. **Reason.** This process will repeat so long at the system does not lose energy. Describe the repeating energy transfers within this system.

SPH4U: Velocity and Frames of Reference

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

All physics quantities that we measure depend on the frame of reference of the observer.

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. Complete the chart showing the measured velocity of each object from each reference frame.

Object	Frame A (Alice)	Frame B (Bob)
Alice		
Bob		
Earth		
Train		

2. 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. 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		

3. 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		

4. 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 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?

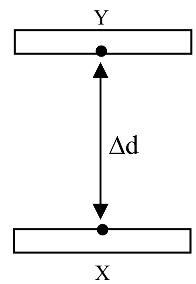
5. Imagine Bob was on an "express" train that travelled at 2×10^8 m/s [E] and turned on his flashlight just as in question 4. What is the velocity of the light relative to Frame A?

6. Alice now has her flashlight turned on and points it east. Bob's same express train passes by. What is the velocity of the light from Alice's flashlight relative to Bob?

SPH4U: The Light Clock

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

Bob is travelling in a spacecraft at a velocity, *v*, relative to the earth. He is carrying with him a light clock – a special kind of clock imagined by Einstein. The clock consists of two perfect, smooth mirrors that face each other and are separated by a distance d. A particle of light (a photon) reflects back and forth between the mirrors which are lined up carefully so that the photon always reflects off the same points. We note two events that take place: event X where the photon leaves the bottom mirror and event Y where the photon reaches the top mirror. The time it takes for the photon to travel between the mirrors represents the 'tick' of the clock.



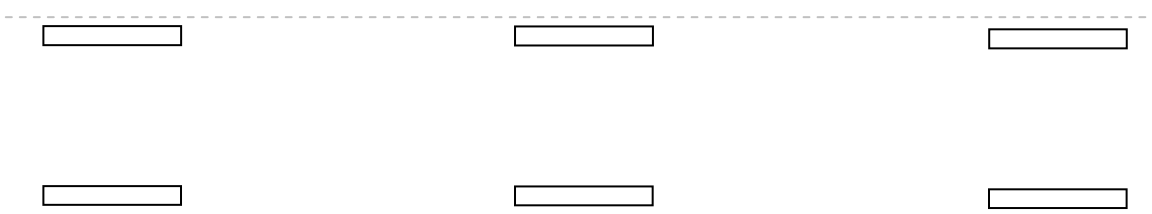
1. Complete the chart of measurements from Bob's frame of reference.

Time interval between events X and Y (one tick)	Δt_o
Velocity of the light clock	
Distance between events X and Y	
Speed of the photon	

2. Construct an equation that relates the speed of the photon to the distance, time it travels as measured in Frame B.

Alice is standing on Earth watching Bob travel by in the rocket ship. She is able to make careful measurements of the light clock and its photon.

3. From Alice's frame, we see the light clock at three moments in time corresponding to three events: the photon at X, the photon at Y and then the photon returning to the bottom mirror. You may assume the rocket is travelling quite fast! Draw the path of the photon through space. Label the distance XY as ΔD.



4. Complete the chart of measurements from Alice's frame of reference. No calculations are required!

Time interval between events X and Y (one tick)	Δt
Velocity of the light clock	
Distance between events X and Y	
Speed of the photon	

5. Construct an equation that relates the speed of the photon to the distance, time it travels as measured in Frame A.

6. Compare the size of the results from each frame.

Measurement	Comparison
Speed of photon	
Distance between X and Y (Δd vs. ΔD)	
Time interval between X and Y (Δt vs. Δt_o)	

Note that both observers **must** agree on the speed of light according to the first postulate of special relativity.

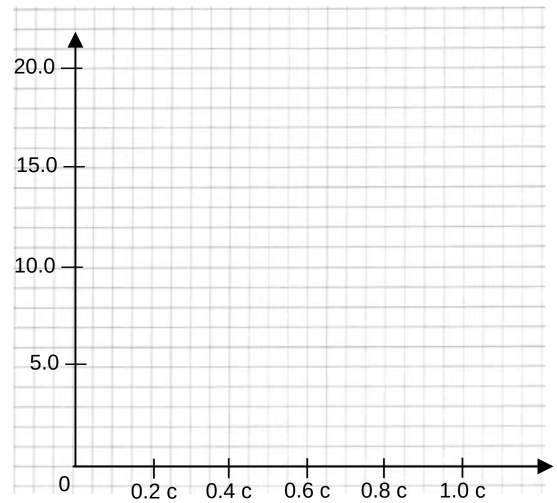
7. Speculate on the implications of your comparisons for the flow of time on the spacecraft!

SPH4U: Why Don't We Notice?

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

1. Complete the chart below. Rewrite the first five speeds in terms of *c*. Calculate γ for each speed. Sketch a graph of γ vs *v*.

Speed	Speed (in terms of c)	γ
Fast Runners, 10 m/s		
Fast Cars, 40 m/s		
Fast Jets, 600 m/s		
The Space Shuttle, 7 860 m/s		
Voyager Space Probe, 17 000 m/s		
	0.1 c	
TV screen electrons	0.3 c	
	0.5 c	
	0.7 c	
	0.9 c	
	0.99 c	
X-Ray Machine Electrons	0.999 c	
LHC protons, 0.999 999 999 95 c		



2. Should the first five γ values you calculate be the same? Explain.

3. Based on the chart, offer a simple explanation for why relativistic effects are not noticed in daily life.

4. What happens to the size of γ as *v* approaches the value *c*?

5. What does this tell us about the flow of time for a highly relativistic object (speeds close to *c*)?

6. Relativistic effects are important for GPS satellites which orbit at a similar speed to the space shuttle 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) Over the course of one day, how much time in seconds does the GPS clock gain or lose compared to a ground clock? Watch your math!

   b) How far does light travel during that time discrepancy? What would be the implication for the GPS system?

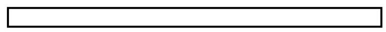
SPH4U: Distance and Velocity

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

Consider the subatomic particle called the muon, μ, that is moving rapidly at a speed, v, relative to a ruler in the direction of the stick's length. We note two events: event A when the muon is at the right end of the ruler, and event B when the muon is at the left end of the ruler. You need a ruler and an eraser (muon) for this investigation.

A: The Ruler's Frame

1. **Represent.** Act out this situation from the frame of reference of the ruler. Say out loud, "A" and "B" when events A and B occur. You will be asked to demonstrate this for your teacher. Sketch this situation and label the two events. Indicate the velocity of the muon v and the distance between the two events Δx_o.



2. **Reason.** An observer in the ruler's frame of reference measures the time interval between the two events. Carefully explain what type of time interval this is. Act this out by showing when you start and stop your pretend stopwatch. What symbol should you use to represent it?

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.** Act out this situation from the frame of reference of the muon. Say out loud, "A" and "B" when events A and B occur. You will be asked to demonstrate this for your teacher. Sketch this situation and label the two events. Indicate the velocity of the ruler v and the distance between the two events Δx.


μ

2. **Reason.** An observer in the muon's frame of reference measures the time interval between the two events A and B. Act this out by showing when you start and stop your pretend stopwatch. Carefully explain what type of time interval this is. What symbol should you use to represent it?

3. **Reason.** What distance does the metre stick travel in this frame of reference?

4. **Represent.** Write an equation that relates speed, distance and time for the metre stick as measured by an observer in the muon's frame.

C: Compare

Compare the size of the results from each frame.

Speed of muon / metre stick	
Time between events A and B	
Distance between events A and B	

1. **Reason.** What can we conclude about the distance measurement of each observer?

SPH4U: Relativity and Energy

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

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:

$$E = \gamma mc^2 \quad \text{where } \gamma = (1 - v^2/c^2)^{-1/2}$$

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 velocity of an object.

2. **Reason.** What other type of energy depends on an object's velocity? What does this tell us about the type of energy Einstein's equation describes?

3. **Reason.** Describe carefully what happens to the energy when the object is at rest. Explain how the equation for E becomes the equation for E_o when the object is at rest. Is Einstein's equation still describing kinetic energy?

4. **Reason.** In other situations, what are some examples of types of energy that may be present when an object is at rest? Excluding thermal energy, what broad category of energy do these types fall into?

5. **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 potential 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 velocity. To the best of our knowledge, this equation is correct under all circumstances and replaces the ones we have previously learned.

6. **Represent.** Write an expression that shows the relationship between E, E_o and E_k.

B: Relativistic Energy

1. **Calculate.** Consider a 1.0 kg block initially at rest. It experiences a force that eventually causes it to reach an impressive speed of 0.6 c. Imagine we had learned nothing about relativity - determine the energies for the "Before Einstein" column in the chart below. Use Einstein's equation to help find the energies for the "After Einstein" column.

	Before Einstein (B. E.)	After Einstein (A. E.)
Rest Energy	zero	
Kinetic Energy		
Total Energy		

2. **Explain.** How do you use Einstein's equation to find the kinetic energy?

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?

Accelerating an object to speeds near that of light is extremely challenging and with our current technology, we can only accomplish this for 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.

4. **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. Explain to your kid sister how much energy would you "need".

5. **Reason.** What does the difficulty of the previous calculation imply about the possibility of ever reaching or exceeding 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 x 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 values. One *electron volt* (eV) is a unit of energy equivalent to 1.602 x 10^{-19} J.

2. **Calculate.** Find the proton's rest mass energy in terms of MeV (10^6 eV).

3. **Explain.** Physicists often write the mass of the proton as 938.3 MeV/c^2. Use the rest-energy equation to help explain why this is a valid unit for mass. Explain why these units make it easy to calculate the rest energy.

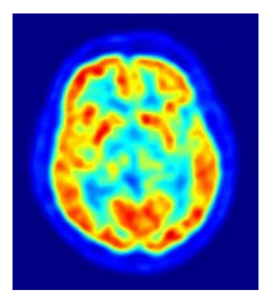
Is it possible to release the energy stored in a particle's mass? You may have already studied the process of nuclear fusion or fission in another course and have learned that, yes, this is possible. In a typical fusion reaction (like in the sun), a deuterium particle (1876 MeV/c^2) fuse with a tritium particle (2809 MeV/c^2) producing a helium nuclei (3729 MeV/c^2) and a neutron (937 MeV/c^2).

$$D + T \rightarrow He + n$$

4. **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.

5. **Calculate.** How much energy is released during the fusion process? Give your answer in joules and electron volts.

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 enti-electron) which collides with an electron of a nearby atom. In the process, the two particles annihilate and produce two gamma-ray photons (γ).



$$e^- + e^+ \rightarrow \text{energy (two photons)}$$

6. **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.

7. **Calculate.** In Star Trek, the main power source for the starship Enterprise is a matter-antimatter engine. How much energy would be produced by annihilating 1.0 L of gasoline (0.720 kg) with 1.0 L of anti-gasoline (0.720 kg)? What form of energy is the annihilation energy transformed into? What speed would that accelerate a typical car (1200 kg) to (use $\frac{1}{2}mv^2$)?

8. **Calculate.** The previous result is quite fast! We should confirm this with a more reliable calculation using Einstein's equation to solve for γ and then v. Use the result for γ explain why the result from #7 was reasonably accurate.

9. **Calculate.** The reverse process can also take place! Energy can be converted into a particle – antiparticle pair.

$$e^- + e^+ \rightarrow \gamma + \gamma \rightarrow p + \overline{p}$$

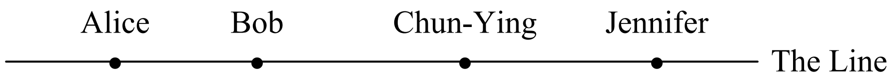
In this case, the extra kinetic energy of the electron-positron pair is converted into the mass of the proton and anti-proton. This is exactly what used to happen at the LEP (Large Electron Positron) collider at CERN in Switzerland. What should the speed be of an electron and positron in the LEP to allow this to happen?

SPH4U: Journey to Flatland

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

A: Lineland

Our first stop is a visit to a very unusual universe that has only one dimension – it is shaped like a line. This universe is inhabited by curious creatures called Liners. They are point-particle organisms that live on "The Line" (as they call their world.) This is the story of the Liners Alice, Bob, Chun-Ying, and Jennifer who are all neighbours on The Line, a portion of which is shown in the diagram below.



1. Let's think about how Liners can move about. In which directions can Chun-Ying move? What will happen when she reaches Bob? How many Liners has she ever physically met?

Bob likes to talk and one day he mentioned to both Alice and Chun-Ying that he likes Jennifer and wishes he could meet her one day. "But promise me you won't tell Jennifer", Bob says to Chun-Ying. "Sure, sure", she replies. The next day Chun-Ying exclaims to Bob, "Jennifer knows you like her!" Bob, shocked, shouts back, "I told you not to tell her!" "I didn't say anything – Jennifer said she heard it from her neighbour Jose", replies Chun-Ying. Bob turns to Alice, "What's going on? How could she find out?" Alice responds, "I don't know, but I did tell my neighbour Elizabeth."

2. How did Jennifer find out? What do the Liners not realize about the shape of Lineland itself?

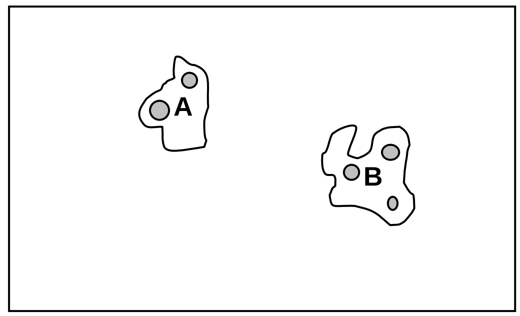
Alice is a Liner physicist. She has studied the theoretical "second dimension" in school, but didn't believe it existed until now. She explains to the others: "Now we know that the directions up and down do exist. But we can't move into the second dimension or see it since it is perpendicular to The Line." The others have never heard of this term: *perpendicular*. Alice continues, "but we can imagine what might happen if Bob could simply walk into the second dimension."

3. Explain what Alice and Chun-Ying would observe if Bob magically moved in a direction perpendicular to the line. Give two reasons why would this be a truly shocking experience for them.

4. Bob returns to The Line, but surprisingly finds himself in between Chun-Ying and Jennifer (what luck!). Explain how Bob did this. How would Bob's complete trip appear to Chun-Ying?

B: Flatland

It's time to leave Lineland behind and travel to a new and more complex universe called Flatland. This universe has two dimensions of space and is populated by colourful and pancake-like creatures called Flatlanders - a portion of Flatland is shown to the right. Its inhabitants move freely in "The Plane" as they call it, moving North and South, East and West. Two Flatlanders, curiously called Alice and Bob, are chatting.



1. Alice says to Bob, trying to make conversation, "You look nice today", she says. How does Bob appear to Alice?

After some chit-chat, Alice holds three rulers and starts talking to Bob about a theoretical third dimension of space. Bob understands the idea of "perpendicular", but then Alice continues by saying that "Up" and "Down" are directions perpendicular to both North-South and East-West. Bob looks very puzzled.

2. Explain why Bob doesn't understand. *Pretend you are Alice and demonstrate these ideas with rulers for your teacher – call your teacher over.*

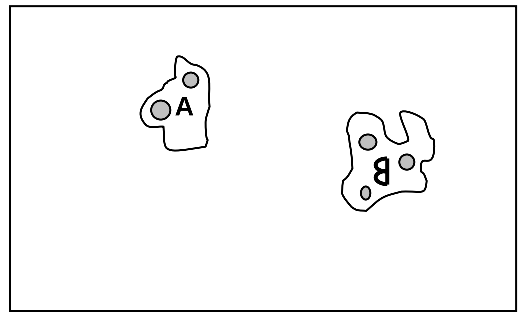
A mysterious voice, seeming to come from every direction, is heard throughout The Plane. "Bob … I will help you understand." A hand reaches into Flatland, grabs Bob and pulls him upwards, perpendicular to The Plane.

3. How would a set of fingers that intersects The Plane appear to Alice? What would she see when Bob is being kidnapped?

Bob looks back at The Plane and shrieks, “Alice, is that you? You look hideous! You have spots! What am I seeing?”

4. Explain what is special about what Bob is seeing and why it is so surprising to him.

“Please put me back! I’m afraid”, yelps Bob. The mysterious hand obliges and places him back in The Plane. After a moment Bob gets back his senses and yells, “What’s wrong with me? Ahh!”



5. What happened to Bob during his trip through the third dimension?

C: Journey to the Fourth Dimension

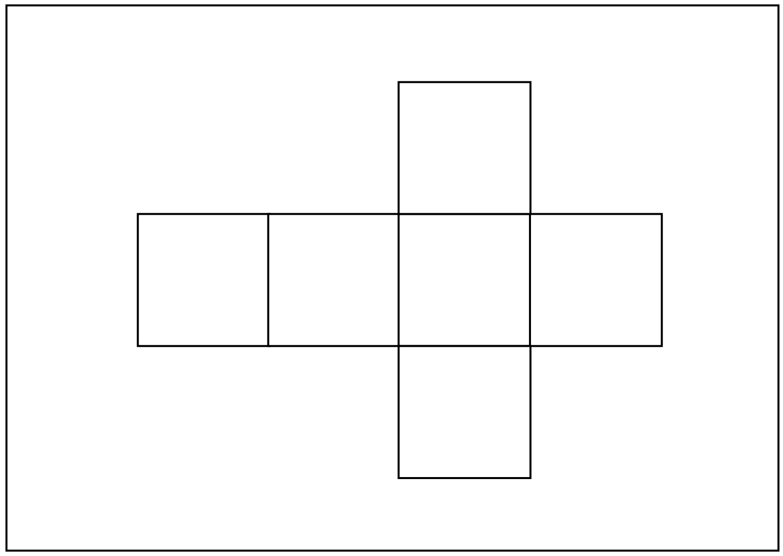
Alice, your physicist friend, is now talking to you about a mysterious fourth dimension of space. She says we can’t see it, or move through it, but it is perpendicular to our three dimensions of space. She knows she can’t point to the fourth dimension using perpendicular rulers so she tries to show you another trick. “Let’s build a four dimensional cube, a hypercube”, she announces.

“Okay, take a straight line and fold it in the second dimension four times, join the ends and you have a square!”

1. Annotate the diagram below, and use arrows to show where the segments move and which ends meet up with which other ends.

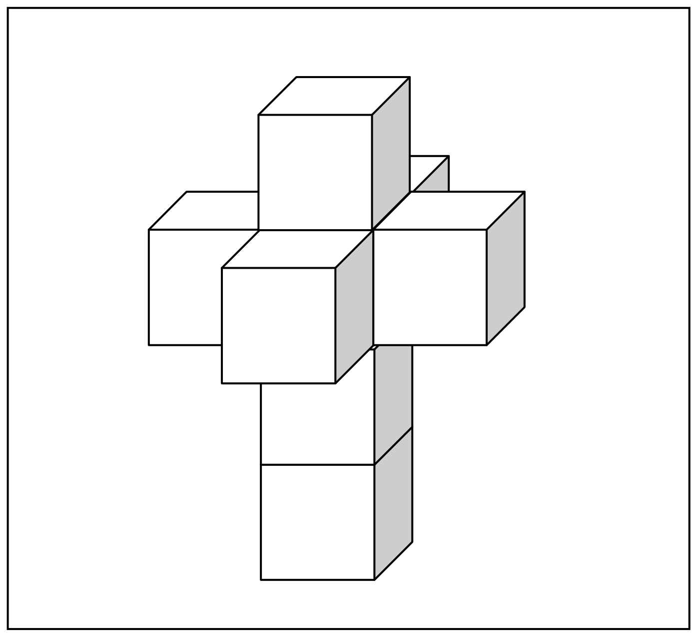
Alice continues, "Now try taking a set of squares, fold them into the third dimension, join up the ends and you get a cube!"

2. Annotate the diagram to the right, and use arrows to show which edges meet up with which other edges.

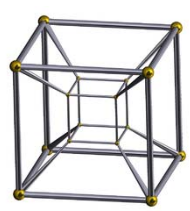


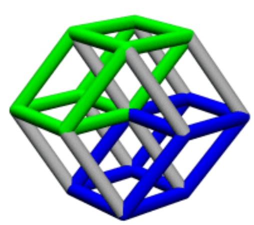
"Now you've got it!" Alice exclaims. "And now, for the grand finale, take a collection of cubes, fold them in the fourth dimension, join up the surfaces and, voila, you've got a hypercube!" This collection of cubes is called a tesseract (see http://en.wikipedia.org/wiki/Tesseract).

3. Annotate the diagram to the right, and use arrows to show which faces meet up with which other faces.



Alice finishes by saying, "we can see 4-D objects in the same way that we can trace the 2-D shadows of a 3-D object on a piece of paper. Position the object or light differently, and you get a differently shaped shadow. Here are some of those 'shadows' for a hypercube." For more, search YouTube for: Dr. Quantum Flatland.





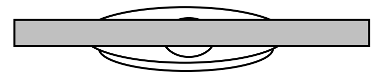
4. What would it look like if a 4-D creature reached in to our 3-D universe, grabbed your neighbour and pulled him out? What would it look like as that slowly hand reaches in?

SPH4U: A New Kind of Interaction

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

A: Observe and Find a Pattern

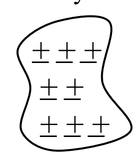
You will need: 2 ebonite rods, an acetate strip and a watch glass. Carefully balance one ebonite rod (rod 1) on the watch glass. Keep it in place with a small ball of tape – see the diagram to the right. Now you are ready to investigate how the ebonite rod interacts with other materials.



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.

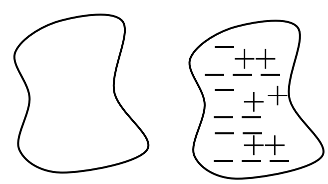
Rod 1 unrubbed	Rod 2 unrubbed	
Rod 1 rubbed with acetate	Rod 2 rubbed with acetate	
Rod 1 rubbed with acetate	The acetate that rubbed rod 1	

2. Identify the patterns in these observations. Don't explain why yet!

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. Therefore, when an object is rubbed, negatively charged particles (electrons) can either be added to or removed from a material. We can represent the electrically charged particles in a material with *charge-pairs* consisting of 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.	Ordinary Matter 

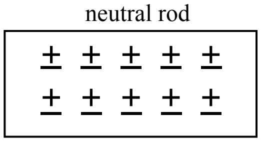
3. **Explain.** What is a charge-pair a simple model of?

4. **Reason**. A student draws a charge diagram of the object shown above after is was rubbed on the left-hand side and gained some negative charge. Explain the errors in the diagram and draw a correct one.



5. **Explain.** Use the charge-pair model to explain the patterns observed in the previous experiment. Draw a charge diagram to help illustrate the two objects in each type of interaction. The ebonite rod exerts a stronger pull on electrons than the acetate.

neutral rod



B: The Unrubbed Rod

Place a fresh, unrubbed rod (rod 1) on the watch glass.

1. **Observe.** Rub one end of another rod (rod 2) with acetate. Bring the rubbed end of rod 2 near rod 1. Describe the interaction you observe.

The atoms and molecules in the ebonite (a plastic) hold their electrons close to the atoms such that the electrons can only shift around the molecules and don't usually travel far away from the molecule.

2. **Explain.** Why do the rods interact as you observed? Complete a charge diagram for each.

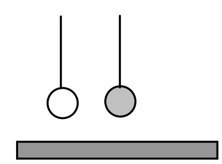
3. **Predict and Test**. You are curious to know what will happen if you rub rod 2 with acetate and bring the **acetate** near the unrubbed rod.

Prediction	Explain your prediction	Observations	Revise your explanation if necessary.

C: The Two Spheres

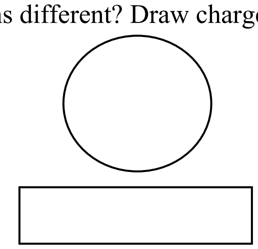
Hang two Styrofoam spheres side by side from the edge of a table. One sphere should be covered in aluminum foil.

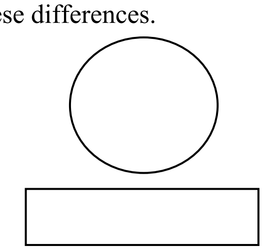
1. **Observe**. **Note:** This experiment work best the first time – once the spheres touch the rod a new effect takes place. Rub a rod with acetate. **Very slowly** bring the rod closer to both spheres. Try to keep the ruler parallel to the table edge. Describe the interaction between the spheres and the rod.



The electrons of some materials are held close to the positive nuclei of its atoms – they may only shift slightly around the nuclei. Other materials have electrons that are quite free to move any distance within the material.

2. **Explain**. Why are the strengths of the interactions different? Draw charge diagrams showing these differences.





3. **Reason**. What can you say about the mobility (freedom to move) of the charges in a metal (conductor) compared with a dielectric (insulator)?

When charges shift within a material and cause the opposite sides of the material to become oppositely charged, we say that the material is *polarized*. Both conductors and insulators can become polarized.

4. **Reason**. Is the ebonite rod a conductor or insulator? Explain how can you decide.

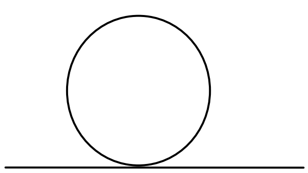
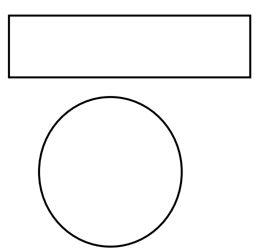
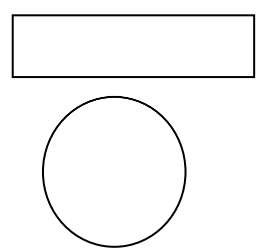
D: Party Time - Confetti

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. When finished, please carefully tidy up the confetti. Try not to get them mixed!

	Predict what you will observe	Explain your prediction	Do the experiment and record your observations	Revise your explanations, if necessary
Paper Confetti				
Aluminum Confetti				

6. **Reason**. Very careful physics experiments, with sensitive scales, show that when you charge an object by rubbing, whether it becomes positively or negatively charged, the mass of the object changes only a very, very tiny amount. This same result is found even when the rubbed object obtains a very strong charge. What do these experiments tell us about the charged particles that get transferred between objects during rubbing?

7. **Explain**. Explain in three steps what happens to the charges of an aluminum confetti particle during this experiment. Draw a charge diagram **and** force diagram 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. 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.

3. **Apply.** Your clothing tends to cling together after going through the dryer. How might this occur in the dryer? Is your answer consistent with what you observed in class? Explain and represent your answer with a diagram.

4. **Apply.** Two conducting spheres have an excess of positive charges and are placed very far apart from one another.

Draw a picture of the spheres when they are very far apart.	Draw a picture of the spheres when they are close together, but not touching.	Draw a picture of the spheres when they are moved far apart again.

F: The Electroscope

An electroscope consists of a vertical metal rod that sticks out of a glass enclosure; a piece of plastic prevents electric charge from going from the metal rod to the enclosure. A pair of thin metal leaves hang down from the bottom of the rod inside the enclosure. Complete the chart below.

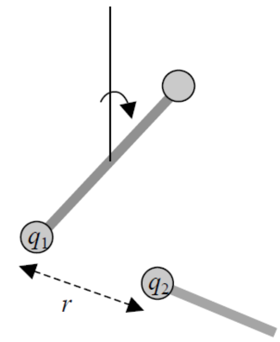
Experiment	**Record your observations.**	**Explain your observations.**
1. Bring a rubbed rod close to the electroscope's top but do not touch. Then remove the rod.		
2. Rub a rod with any material and then rub the top of the electroscope with the rod.		
3. Touch the top of the electroscope with your hand.		
4. Bring the rubbed rod to the electroscope; while it is being deflected, place your hand on the electroscope then remove your hand; after remove the rod.		

1. **Explain.** What is "grounding" and why does grounding a charged object discharge it?

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 an identical uncharged metal sphere.



A: Looking for Patterns

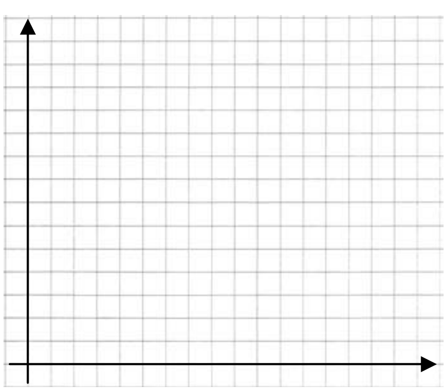
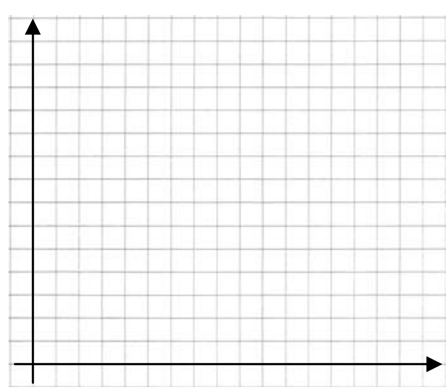
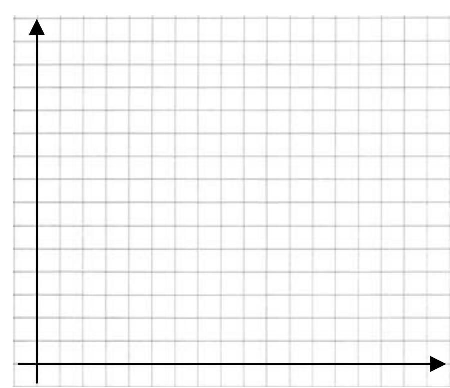
1. Explain the mechanism behind his method of dividing the charge and provide an illustration. Why did he have to use metal spheres? Would plastic spheres work?

2. In Coulomb's experiment, which quantity is the dependant variable? Which are the 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".

Experiment	**Charge q_1**	**Charge q_2**	**Distance r**	**Force $F_{q_1 \text{ on } q_2}$**
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.

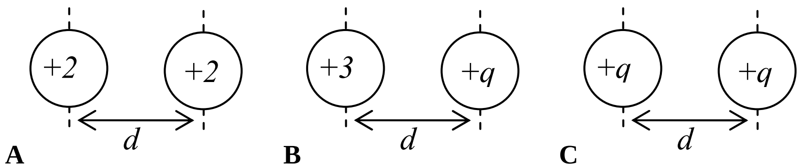
B: Coulomb's Law

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 electric force that object 1, with electric charge q_1, exerts on object 2, with electric charge q_2, 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 2, with electric charge q_2, exerts on object 1, with electric charge q_1:

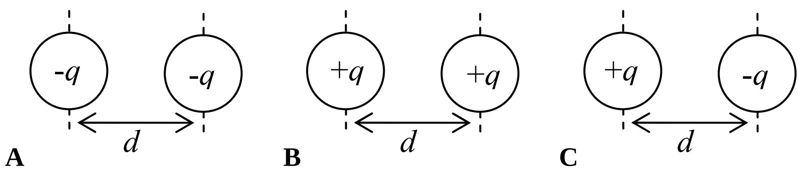
$$\left|F_{q_1 \text{ on } q_2}\right| = \left|F_{q_2 \text{ on } q_1}\right| = \frac{k|q_1||q_2|}{r^2}$$

where $k = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$. We assume that the objects are much smaller than their separation r (i.e. point-like objects).

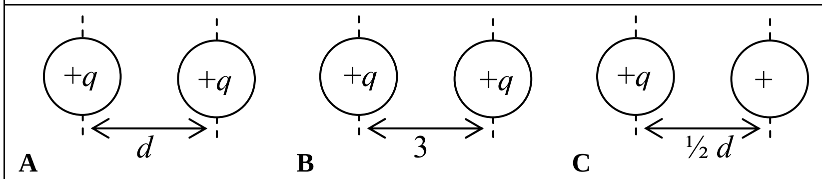
1. The diagrams show two charged objects and their separation. Rank the size of the force that the left object exerts on the right object from the strongest to the weakest force. Explain how you made the ranking.



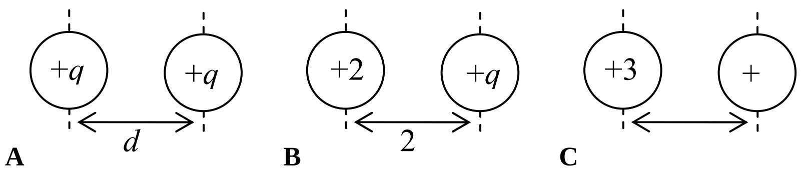
Ranking:
Why:



Ranking:
Why:



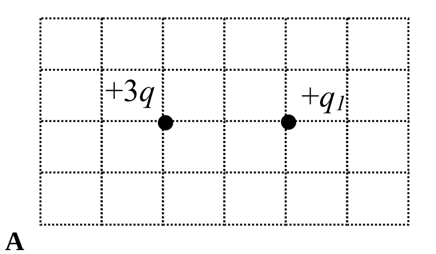
Ranking:
Why:

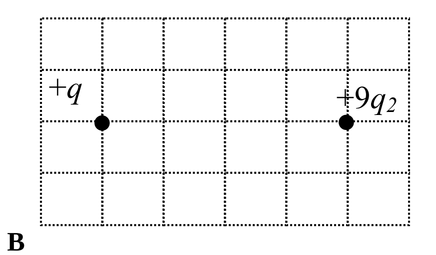


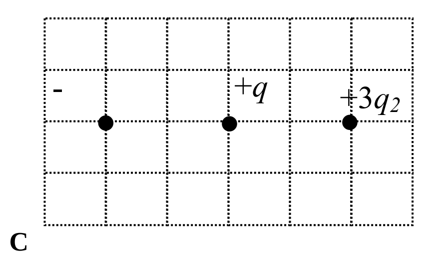
Ranking:
Why:

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 objects are fixed on a grid. All charged objects q_1 are identical. All other charged objects are a multiple of q_2. Draw a force diagram for each charge q_1, then rank the magnitudes of the net electrical forces experienced by q_1. Provide a brief explanation for your ranking.





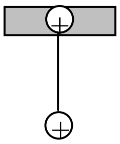
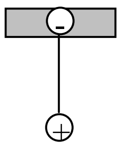


SPH4U: Analyzing Electrical Forces

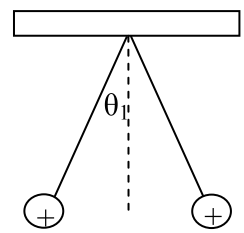
Recorder: ___________________
Manager: ___________________
Speaker: ___________________
0 1 2 3 4 5

A: Combinations of Interactions

1. **Represent and Reason.** A positively charged sphere with charge q and mass m hangs at rest on the end of a string. Another positively charged sphere of a different charge $5q$ is secured at the top end of the string to a wooden support. Fill in the table that follows.

Illustration	**Force Diagram for lower sphere**	**2^{nd} law for hanging sphere**	**Draw 3^{rd} law electrical force pairs**
			
Top sphere is now negative 			

2. **Represent and Reason.** Two equal-mass stationary spheres are attached to the end of 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 $+Q$. Each string makes an angle **less than 45°** with respect to the vertical. Fill in the table that follows.



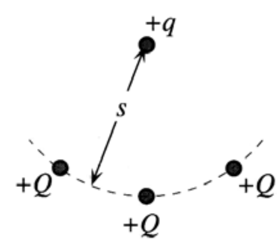
Draw a force diagram for the left sphere.	Draw a force diagram for the right sphere.	Which angle is bigger? Explain.	Use 2^{nd} law for the right sphere.	Rank the F_T, F_e, and F_g, from largest to smallest. Explain.

3. **Equation Jeopardy.** The application of Newton's second law for a positively charged object at one instant of time is shown in the equation that follows. Other charged objects lie along a horizontal line. Complete the table.

$$(9.0\times10^{9}\,Nm^{2}/C^{2})\left[-\frac{(2.0\times10^{-4}\,C)(3.0\times10^{-5}\,C)}{(2.0m)^{2}}-\frac{(9.0\times10^{-4}\,C)(3.0\times10^{-5}\,C)}{(3.0m)^{2}}\right]=(4.0kg)a_{x}$$

Draw a force diagram.	Sketch the situation the equation might describe.	Write in words a problem the equation solves.

4. **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.*"

(a) Do you agree with either student? Explain.

Force Diagram

(b) Draw a force diagram for the charge q.

(c) What, if anything, can be said about the magnitude of the net force on the charge $+q$? Explain.

5. **Apply.** Four identical charges $+q$ are placed at the corners of a square with side length d. On a large whiteboard, find the net force experienced by one of these charges. When done, call your teacher over. Each member of your group will help to explain the solution. Once approved, take a photo of the whiteboard for your notes.

SPH4U: Picturing Electric Forces

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. Which force is that?

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.				

One way of explaining how gravity can have an effect on objects far away is with the idea of a *field*. We say that the earth has a gravitational field that extends throughout space and that the earth is the *source* of the field. The earth acts on distant objects through its gravitational field.

B: In Search of the Electric Field

For this investigation you will need an electroscope, an ebonite rod, an acetate strip, a Styrofoam cup and a piece of aluminum foil. 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 atop 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 around the rod 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. The properties of a test particle are such that it does not affect the field of the source (its charge and size are small).

3. **Observe**. Place the electroscope on a table and bring the charged rod nearby. Place the piece of paper between the rod and sphere – **don't let them touch!** Observe. Next, place the aluminum foil between the rod and sphere – **don't let them touch!** Observe. What effect do different materials have on an electric field?

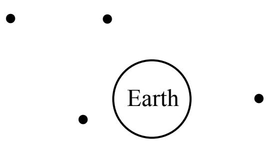
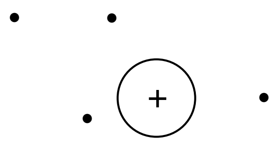
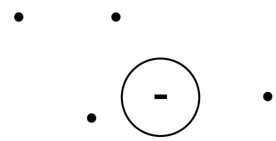
4. **Apply.** How would you protect sensitive electronics from unwanted electric fields?

Adapted from Van Heuvelen, *Physics Union Mathematics,* Rutgers University, 2010

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? Try it out!

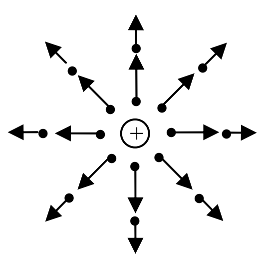
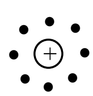
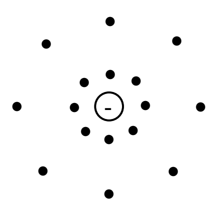
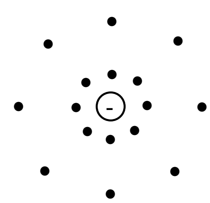
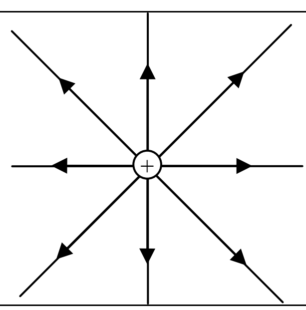
C: Picturing the Electric Field

1. **Represent and Reason**. For each situation pictured below, represent with arrows the gravitational force or the electric force that a test particle would experience due to the sources at the points shown. In the study of electricity we will always choose **all test particles (test charges) to have a positive charge**.

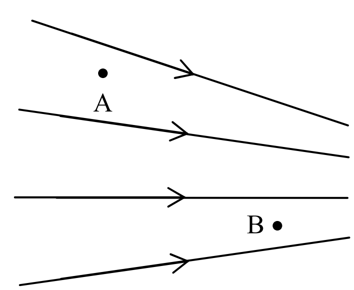
The planet Earth	An object with a large positive charge	An object with a large negative charge
		

A force field (a field representing forces) is a way of representing the force vectors due to a source 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 **electric** fields:
(1) Electric field lines follow the "path" of the vectors. The vector is always tangent to the field line.
(2) E-field lines start on positively charged objects and end on negatively charged objects.
(3) The magnitude of the field at a point is represented by the density or concentration of the lines near that point.
(4) A corollary to this idea is that the number of lines leaving or terminating on a charged object is proportional to the magnitude of its electric charge.

2. **Represent and Reason**. The table below gives four examples of point-like charges objects. Study the given examples and draw E-field vectors and E-field lines for each source.

	(a) a charge of $+q$	(b) a charge of $+2q$	(c) a charge of $-q$	(d) a charge of $-2q$
Electric Field Vectors				
Electric Field Lines				

3. **Apply.** A region of space has an electric field as shown to the right. Note that we do not know the location of the source of this field. A particle with a **negative** charge is placed at point A and then at point B. Draw the force vectors at positions A and B. Explain how to decide the direction of the force on the particle at that position in space. Explain in terms of the field line density how you determined the lengths of the vectors.

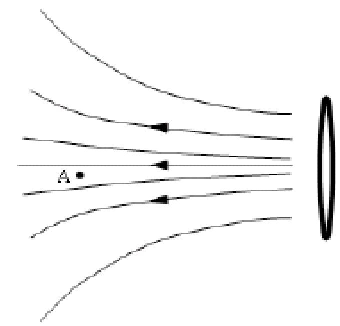


SPH4U: The Field Concept

The idea of the field is fundamental to modern physics. An object or a system of objects is the *source* of the field. An additional 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 our 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

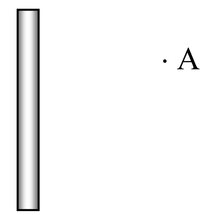
6. **Reason**. Based on the better definition you found above, what are the units of the wind field?

7. **Summarize**. Does the wind force depend on the fan, the kite, or both? What about the wind field? Explain.

B: 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.

A glass rod is given a positive charge by rubbing it with silk. You hold a bead with a small charge at point A. Then you pull it away and hold a bead with a larger charge at that same point.



1. **Reason.** Is there an intuitive sense in which the bead with more charge feels a greater "electric effect" from the rod at point A? Explain. Does that sense correspond to a larger electric force, a larger electric field, or both?

2. **Reason.** Is there an intuitive sense in which both beads feel the same "electric effect" from the rod at point A? Explain. Does that sense correspond to the same electric force, the same electric field, or both?

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 (i.e., how much force it feels)? In a given electric field?

4. **Summarize.** Does the electric field felt by a bead at point A depend on the charge of the rod, the charge of the bead or both? Explain.

C: Defining the Electric Field

When held at point B, a bead of charge 2.0 nanocoulombs is repelled by the rod with a force of 10 N. The charge on that bead is now doubled, to 4.0 nanocoulombs, and the bead is again held at point B.

1. **Reason.** What force do you expect the bead now feels from the rod? Explain.

2. **Reason.** Now a bead of charge 5.0 nanocoulombs is held at B. What electric force do you expect it feels from the rod?

3. **Reason.** So, the 2.0, 4.0, and 5.0 nanocoulomb beads feel different electric forces at point B. But the electric field at B is the same no matter which bead you hold there, just as the wind field at a given point in front of the fan doesn't depend on which kite you hold there. Is there some number having to do with electric force and bead charge that's the same for all three beads at point B and could therefore formalize the concept of electric field?

4. **Reason.** Let's explore the meaning of the number and equation you just chose. What are the units of that number? Explain what that number means, and why it corresponds to the notion of electric field, in terms your roommate could understand.

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 bead or other particle placed in the field; and let F denote the electric force felt by that particle. Write an equation relating E, q, and F.

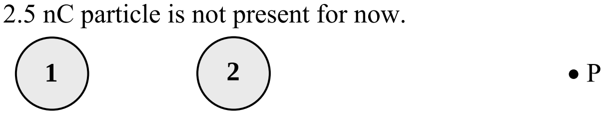
*** call your teacher to check your result ***

5. **Summarize.** Now let's compare three similar examples of fields: wind, gravitational and electric. Summarize the comparisons in the chart below.

	Wind	**Gravitational**	**Electric**
Property of an object that determines how much force it experiences.			
Units of field			

D: Problem Solving

In the diagram below, beads 1 and 2 carry charges 1.0 nC (nanocoulombs) and 2.0 nC, respectively. P is just a point in space, not a charge. The electric force exerted on bead 2 by bead 1 is 12 N. The overall electric force that would be felt by a 2.5 nC charge at point P is 20 N; but a 2.5 nC particle is not present for now.



First let's think about the effect of bead 2 on bead 1.

1. **Reason.** Find the electric force exerted by bead 2 on bead 1. Yes, you have enough information; use a basic law of physics!

2. **Calculate.** Find the electric field due to bead 2 at the location occupied by bead 1.

3. **Reason.** Is your D#2 answer greater than, less than, or equal to the electric field due to bead 1 at the location occupied by bead 2? Explain.

4. **Reason.** Given that beads 1 and 2 feel different fields, it's reasonable to expect that they also feel different forces. But they don't! To reconcile this apparent conflict, explain in intuitive terms how beads 1 and 2 can end up experiencing the same force even though they feel different fields. Hint: Think of a bigger and littler fan facing and blowing on each other.

5. **Reason.** The charge on bead 1 is now tripled. How does that affect:
   (a) the electric field due to bead 2 at the location occupied by bead 1? Explain.

   (b) the electric field due to bead 1 at the location occupied by bead 2? Explain.

   (c) the force felt by bead 2? Explain.

   (d) the force felt by bead 1? Explain.

Adapted from *Tutorials in Physics Sense-Making,* University of Maryland Physics Education Research Group, Spring 2008.

SPH4U: The Superposition of Fields

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

A: Two Sources and Only One Field, Ja!

You will need one electroscope, a piece of wool and a balloon.

1. **Observe.** Vigorously rub the wool against the balloon and hold it near the electroscope. Remove the wool and hold the balloon near the electroscope. Describe your observations.

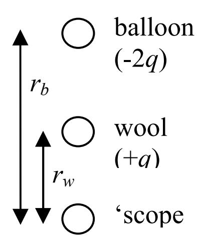
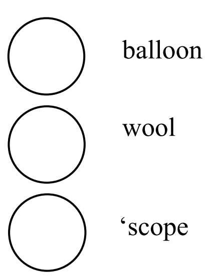
2. **Reason.** Is there anything different about what's happening to the charges inside the electroscope when the wool or balloon is brought near? Explain.

3. **Predict**. You will hold the freshly rubbed wool very close to the electroscope's sphere. Then, starting from far away, slowly bring the balloon close. What will initially happen to the electroscope leaves? (Note: When the balloon is very close, something different will occur.)

4. **Observe and Reason**. Try it out and record your observations. What can we say about the combined effect of the two objects on the electroscope? What is the strength of the electric field at the position of the electroscope sphere? Explain.

> Electric field vectors are related to force vectors (they are the force per unit charge). When there are multiple sources, we can construct a type of force diagram for electric fields which shows the individual electric field vectors at a point in space due to each source. Just like with forces, we can then find the total or *net electric field*: $\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + ...$ In fact, we can work with field vectors using all the same techniques as force vectors (force diagrams, sign conventions, etc.)

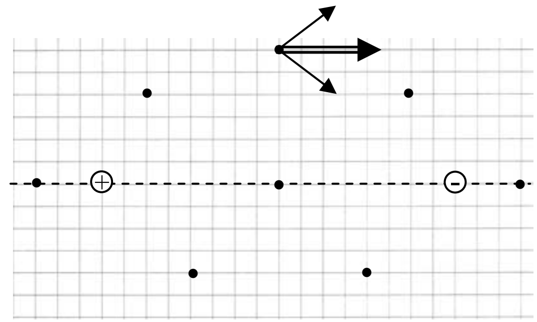
5. **Represent**. The balloon and wool are positioned such that the electroscope leaves are vertical. We represent the balloon, wool and electroscope sphere as point-like particles (or small spheres). We assume the balloon has twice the charge as the wool. (a) Complete the charge diagram below for each object. (b) Draw a force diagram for a positive test particle in the electroscope sphere showing the *electric field vectors* of the two source objects. (c) Write a complete equation for the net force experienced by the test particle. (d) Write a complete expression for the net field vector at the position of the test particle. What are these equations equal to?

Diagram	Charge Diagram	Force Diagram	Net Force Equation	Net Field Equation
				

*** check with your teacher before continuing ***

B: Let's See 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 to the right. Draw a force diagram at each point for the electric field due to the individual sources– simply estimate their magnitudes. With a different colour, draw a vector to represent the net field at each point (if you are familiar, use the parallelogram trick).

2. **Predict.** Review the rules for electric field lines. Use the net field vectors you found to help construct the field lines for the two charges on the grid below.

3. **Observe.** Use the applet: http://www.falstad.com/vector3de/ Select "dipole" for the field selection and select "Display: Field Lines". Make any changes to your prediction if necessary.

4. **Reason**. Why do field lines never cross?

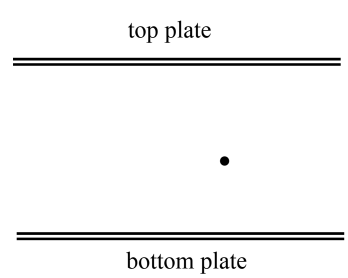
5. **Apply**. What are some realistic examples of systems with the field of a dipole (think of chemistry examples!)

6. **Predict**. What will happen to the net electric field if the distance between the positive and negative charge becomes very small (small enough we can't notice it)? Explain your prediction.

7. **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: Charged Plates

Another important electric field example is the field that exists between two parallel metal plates that have opposite electric charges. Use the applet and set the field to "charged plate pair". Make the sheet size as large as possible and increase the field line density.



1. **Observe**. Draw the field lines. How do the directions of the field lines that are away from the edges compare with one another?

2. **Apply**. A negatively charged particle is placed between the plates as shown in the diagram. Assume the field lines are pointing upwards and gravitational effect can be ignored. Describe the motion of the particle if:
   (a) it is initially at rest.

   (b) it is initially moving upwards.

   (c) it is initially moving left.

SPH4U: Magnetic Fields

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

A: Searching for a Field

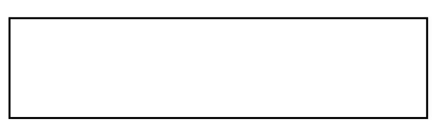
You need a bar magnet and a compass.

A compass is a special device whose north end points in the direction of the magnetic field at that position in space.

1. **Observe.** Check that your compass works – it should jiggle at the slightest touch. 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 and Reason.** How does the interaction of the magnet and compass depend on the distance from the bar magnet and its location around the bar magnet? How can you tell? Modify any of your field vectors if necessary.

3. **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 of 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.



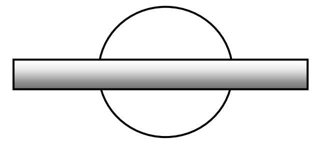
4. **Explain**. Point out two regions where the field strength is particularly strong and weak. How can you tell?

B: The Birds and the Bees of Magnetism

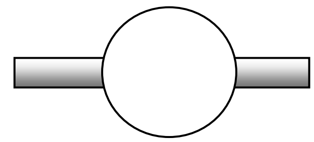
You need an alligator wire, a compass and a 9V battery. WARNING: Never clip both ends of the wire to the battery – it will over heat!

1. **Observe.** Clip only one end of the wire to the battery. Move the middle of the wire around the compass. Describe your observations. Is there any evidence for a magnetic interaction between the compass and the wire?

2. **Observe.** Place the wire over the top of the compass such that it is parallel to the needle. 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 conventional current flow and the compass needle. Is there any evidence for the existence of a new magnetic field?



3. **Observe**. Now hold the compass just above the wire. Repeat your observations.



Magnetic fields ($\vec{B}$) are created by **moving** 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: ⊗

4. **Observe and Explain**. Use the applet: http://falstad.com/vector3dm/. 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? Explain.

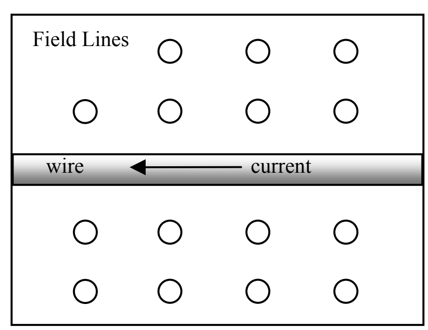
Field Vectors

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!

Field Lines

The *Right Hand Rule for Current Flow* relates the motion of positive charges (conventional current) and the magnetic field they create. When the thumb of your right hand points in the direction of the conventional current, your fingers curl in the direction of the magnetic field lines.

6. **Predict** Imagine the wire is oriented across our page as shown below. It is difficult to draw the field lines 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 lines 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

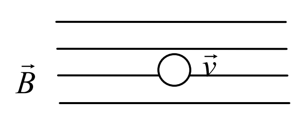
2. **Reason**. Is there any evidence from your observations for the existence of a magnetic interaction between a charged object at rest and a magnetic field? Justify your answer using your observations.

B: Charges on the Move

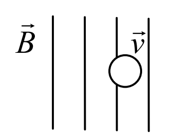
This is a class demonstration. We want to study the interaction between a magnetic field and moving charges. An oscilloscope tube and high tension power supply will produce moving charges. A permanent magnet will provide the magnetic field.

1. **Observe and Reason**. The power supply is turned on and an electron beam reaches the phosphorescent screen of the tube. Record your observations. What is the direction of the conventional current?

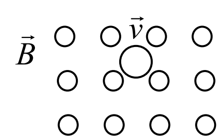
2. **Observe**. The bar magnet is held perpendicular to the beam with the north pole beside the tube. To a good approximation the magnetic field points straight out from the end of the bar magnet. Record your observations. Complete the diagram showing the velocity of the current, the magnetic field and the force acting on the charges.



3. **Observe**. The bar magnet is held perpendicular to the beam with the north pole above the tube. Record your observations and complete the diagram.



4. **Observe**. The bar magnet is held parallel to the tube with the north pole pointing towards you. Record your observations and complete the diagram. Why do the field lines look so different in this example?



5. **Reason**. 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 charge in a magnetic field is given by: $F_m = qvB\sin\theta$, 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 field lines and the velocity. The direction of the force is determined by the *Right Hand Rule for Magnetic Forces*: The thumb points in the direction of the **conventional current**, the fingers in the direction of the magnetic field lines and the palm of your hand points in the direction of the force.

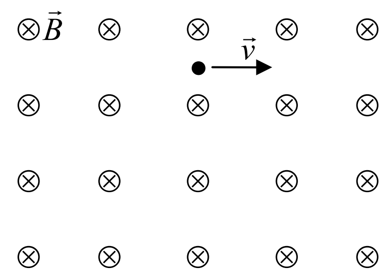
6. **Reason.** Use the equation for the magnetic force to verify your conditions from the previous question. Explain.

7. **Predict**. Use the right 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.

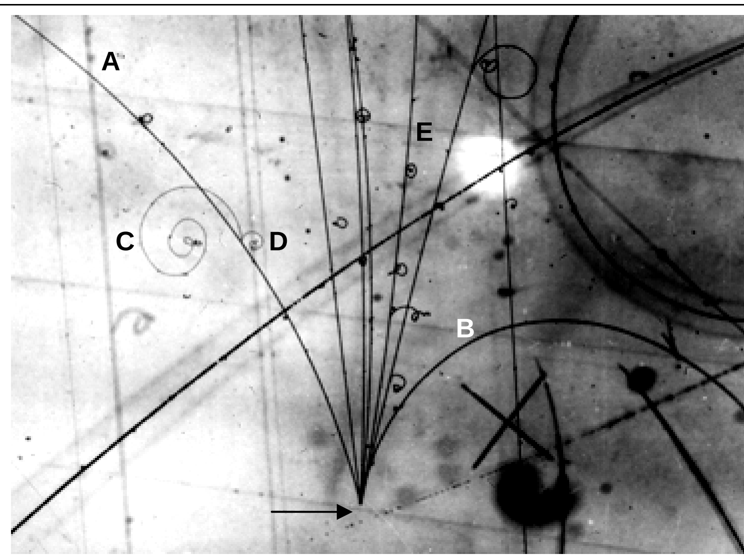
2. **Reason**. A short moment later, where might the electron be located? Draw it and its new velocity vector. At this later moment, what will the direction of the force be? Draw this on the diagram. Explain.

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.

C: Bubbles, Tiny Bubbles

The image to the right shows the paths of particles travelling through a bubble chamber, a chamber of superheated fluid. When a charged particle interacts with an atom of the fluid, a bubble forms. This creates a bubble trail behind the particle. A strong magnetic field passes through the bubble chamber and is oriented out of the page. The trails of five particles are labelled.



1. **Apply**. What is the charge of the particle that produced each trail? Explain how you can tell.

2. **Apply**. Rank the **momentum** of the particles that produced each trail. Explain.

3. **Apply**. Why do you think trails C and D spiral inwards?

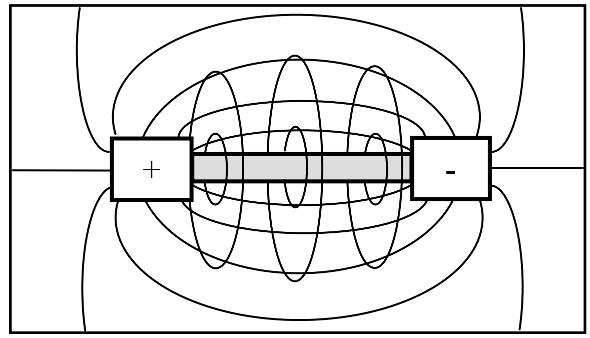
SPH4U: Electromagnetic Disturbances

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

We have studied the creation of both electric and magnetic fields separately, but not it is time to build up the complete picture of what happens when current flows through a wire.

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.



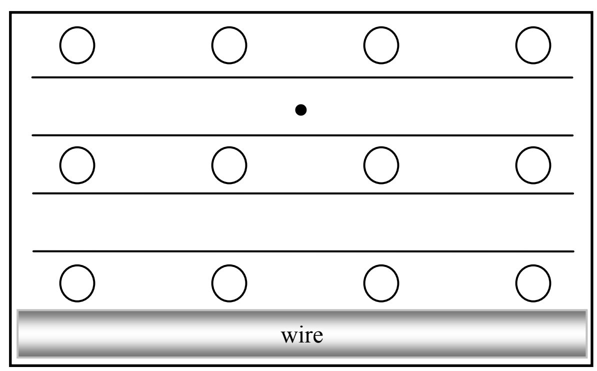
1. **Represent.** Choose a colour to represent the conventional current. Draw an arrow that represents the flow of conventional current.

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.



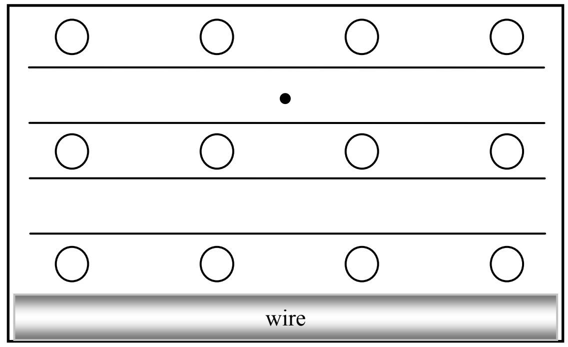
1. **Represent.** Complete the diagram by: (a) labelling and colour coding the electric and magnetic field lines and (b) showing the direction of all the field lines and current

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. **Observe.** Click "Stopped" to freeze the animation and confirm the two illustrations above. Explain carefully how both the strength and magnitude of the two fields are represented in the simulation.

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).

10. **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) Energy from this wave may be absorbed by causing other charges to accelerate (our distant charge).
3) The frequency of the wave's oscillation and the properties of the object containing the distant charge determine how much that charge will respond to the wave and how much energy it will absorb. (a kind of resonance)

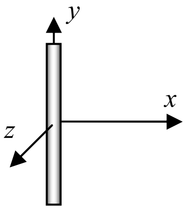
SPH4U: Understanding EM Waves

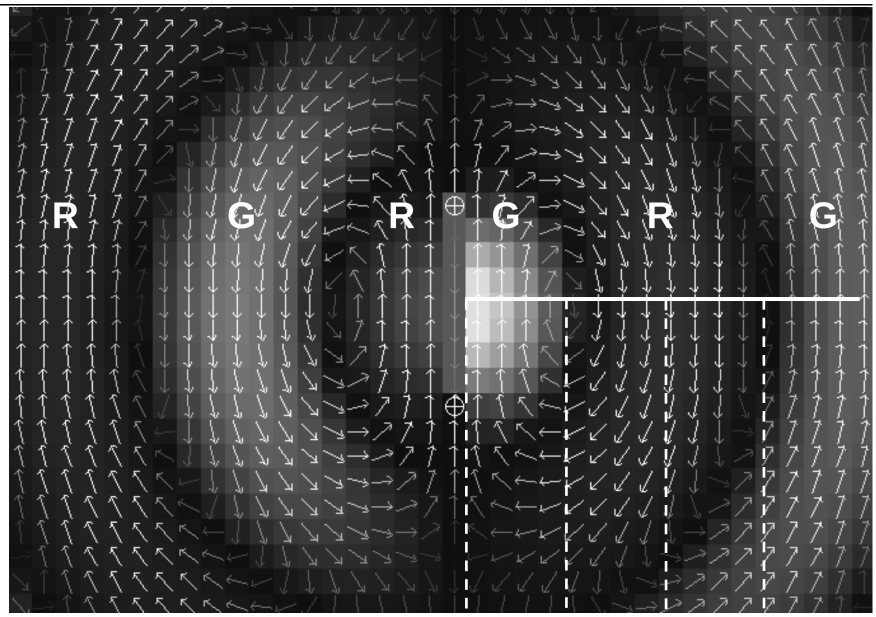
Recorder: __________________	
Manager: __________________	
Speaker: __________________	
0 1 2 3 4 5	

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.

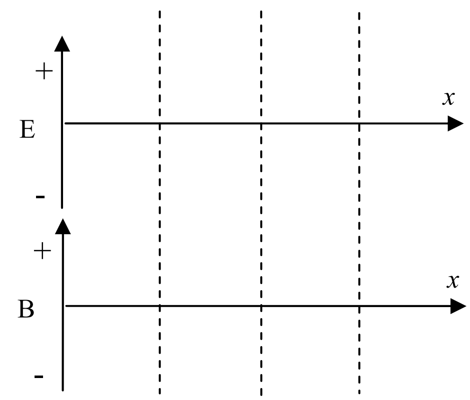
A: The Line Model of an Electromagnetic Wave

To the right is 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.



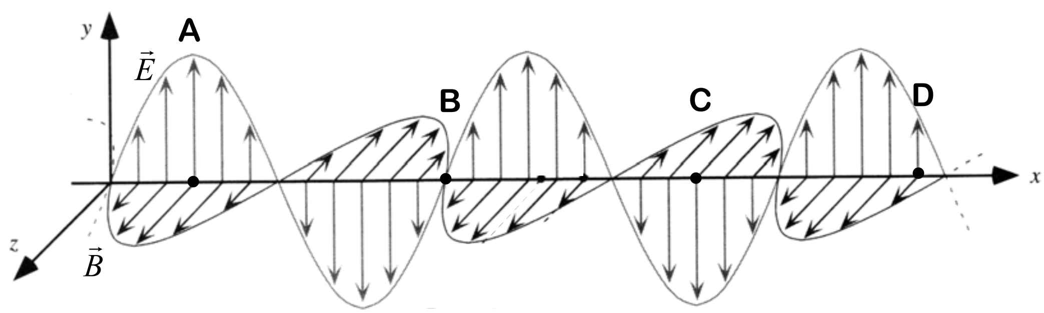


1. **Represent.** Imagine we draw a line along the *x*-axis starting at the surface of the wire. **Remember** that the simulation does not show the field strength using the arrow lengths. Sketch a graph of the electric field vs. position along the *x*-axis along the line. Do the same for the magnetic field. Upwards is positive for the E-field and outwards 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. Explain.



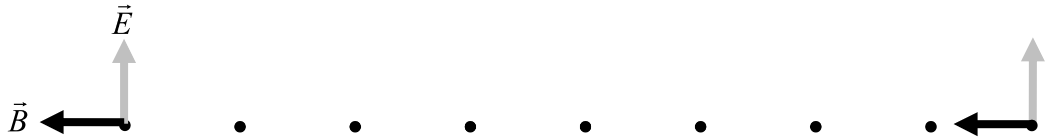
3. **Reason**. How do the directions of the electric and magnetic fields compare at point C? How about at any point?

4. **Reason.** The line model represents the fields at one moment in time, t_o. The EM wave is travelling outwards from the wire and is changing in time. What will the graph look like at a time t_1, a very short time interval after t_o? Trace the E-field part of the wave on the diagram above.

5. **Reason**. Draw the electric field vectors for each point at moments t_o and t_1.

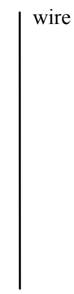
A: t_o ● t_1 ●   B: t_o ● t_1 ●   C: t_o ● t_1 ●   D: t_o ● t_1 ●

6. **Represent**. Imagine we watch the changing field vectors at point A as time goes by from the front view (looking along the x-axis towards the wire). Draw a sequence of arrows that represents the field vectors after equal intervals of time during one cycle of the EM wave.



B: Wave, Meet Conductor. Conductor, Meet Wave.

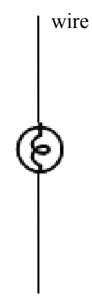
Imagine that the EM wave depicted above in question #2 is a radio wave. It now passes by a long, thin conducting wire that is oriented along the y-axis.



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.** As the wave propagates past the wire, would the magnetic field due to the wave cause the charges in the wire to move in a direction along the length of the wire? Explain.

3. **Reason.** Imagine a 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 is oriented parallel to the y-axis. Would the bulb ever glow? Explain.



4. **Reason.** Would it glow if the wire was oriented parallel to the z-axis? Explain.

5. **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 fields of the wave cause charges in the antenna to accelerate transferring electromagnetic energy from the wave into the electrical energy of the moving charges. An electric current is created or *induced* and this current can be passed into a circuit providing a radio station signal, a Bluetooth signal, a wireless router signal, a TV signal, a cellphone signal, … so many possible signals!

6. **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 wave? Explain.

Adapted from McDermott and Shaffer, *Tutorials in Introductory Physics.* Prentice Hall, 2002

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.

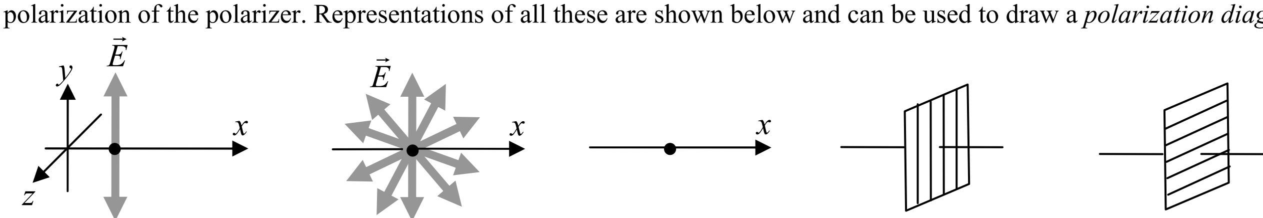
A: Through the Polarizing Glass

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?

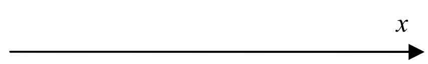
2. **Observe.** Hold a second polarizing filter in front of the first, and look at the room lights again. Describe how the filter affects the light you see. How does rotating one of the filters with respect to the other affect what you see?

If the electric field in all parts of a light beam oscillates along a single axis, the light beam is said to be *linearly polarized.* The direction along which the electric field oscillates is called the *direction of polarization* of a light beam. If the electric field oscillated in different, random directions within the same beam, that beam is said to be *unpolarized*. The light transmitted by a polarizing filter (or *polarizer*) depends upon the relative orientation of the polarizer and the electric field in the light wave. Every polarizer has a *direction of* polarization, which is often marked by a line on it. The electric field of the transmitted wave is equal to the component of the electric field of the incident wave that is *parallel* to the direction of polarization of the polarizer. Representations of all these are shown below and can be used to draw a *polarization diagram.*

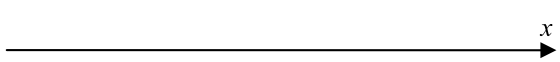


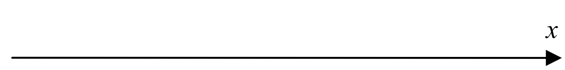
polarized beam | unpolarized beam | no beam | filter with vertical direction of polarization | filter with horizontal direction of polarization

3. **Represent**. Draw a polarization diagram showing the result of an unpolarized beam passing through a single polarizing filter (your choice).



4. **Reason and Represent.** Do the room lights produce polarized light? Explain how you can tell from your observations. Draw a two polarization diagrams that illustrate your explanation.

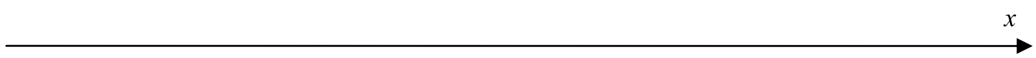




5. **Observe**. Describe other sources of polarized light from around the classroom or amongst your belongings.

6. **Reason.** Describe how you should orient the polarizers with respect to one another so that the light transmitted through the polarizers would have (1) maximum intensity or (2) minimum intensity.

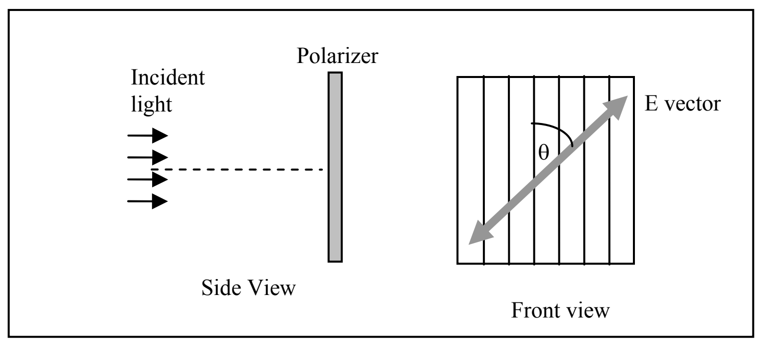
7. **Represent**. Draw a polarization diagram for the situation of minimum intensity you described above.

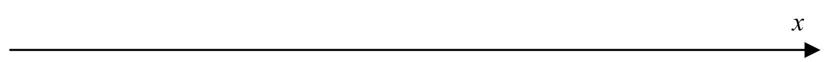


When two polarizers are oriented with respect to one another such that the light is at a minimum intensity, the polarizers are said to be *crossed*.

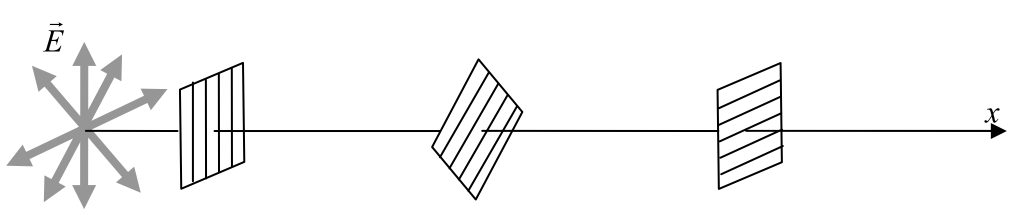
8. **Reason.** Suppose that you had a polarizer with its direction of polarization marked. How could you use this polarizer to determine the direction of polarization of another unmarked polarizer? Explain your reasoning.

9. **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_o. Write an expression for the amplitude of the transmitted component of the electric field. Represent this in a polarization diagram.





10. **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 direction of polarization makes a 45^o angle with both filters is placed between two crossed filters? Explain and draw a polarization diagram. We will test this as a class.



Adapted from McDermott and Shaffer, *Tutorials in Introductory Physics.* Prentice Hall, 2002

SPH4U: Modelling 2-D Waves

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

A: You Have Seen the Light

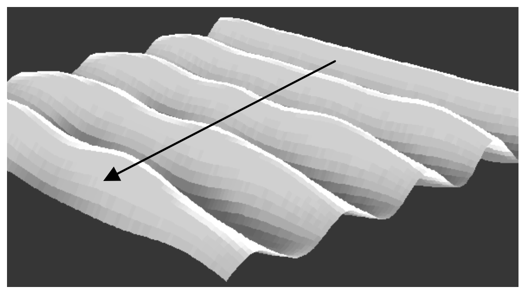
Something interesting can happen when a wave of light enters your eye. At the front of the room a light bulb is set up.

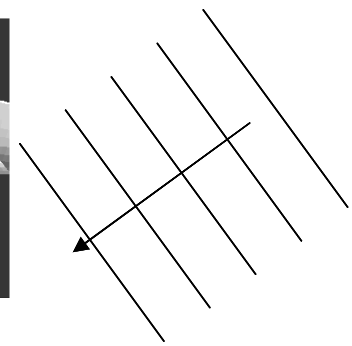
1. **Observe.** Describe and sketch what happens to the light from the bulb as you gradually close your eyes until there is only a tiny, tiny opening.

2. **Observe.** Keep your eyes mostly closed. Describe what happens when you tilt your head.

B: Picturing Two-Dimensional Waves

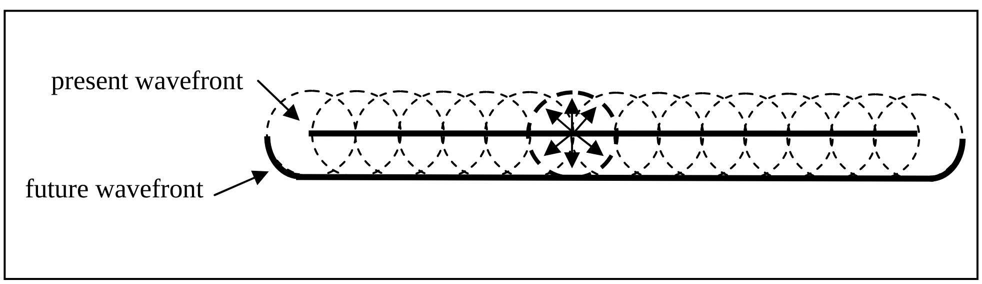
So far when we have described light waves, we have pictured waves travelling along a single line in space. What do they look like when we picture them traveling in a plane? We can draw pictures resembling the surface of water. Consider the illustration from the simulator www.falstad.com/ripple/. We can easily sketch of 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*.





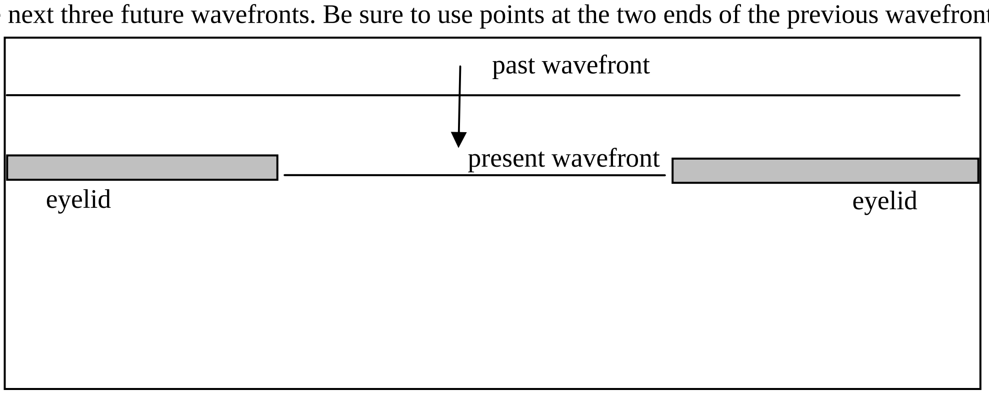
To understand how a 2-D wave works, we use an idea proposed by Christian Huygens in 1690. The fundamental wave motion is circular – imagine a pebble dropped in water and a circular wave rippling outwards. Huygens proposed that each point along a wave front can be considered to be a *point source of circular 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 penny and draw a dot every penny radius along the present wavefront. Be sure to centre the penny at the two ends as well! Next, trace the outline of the penny 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.

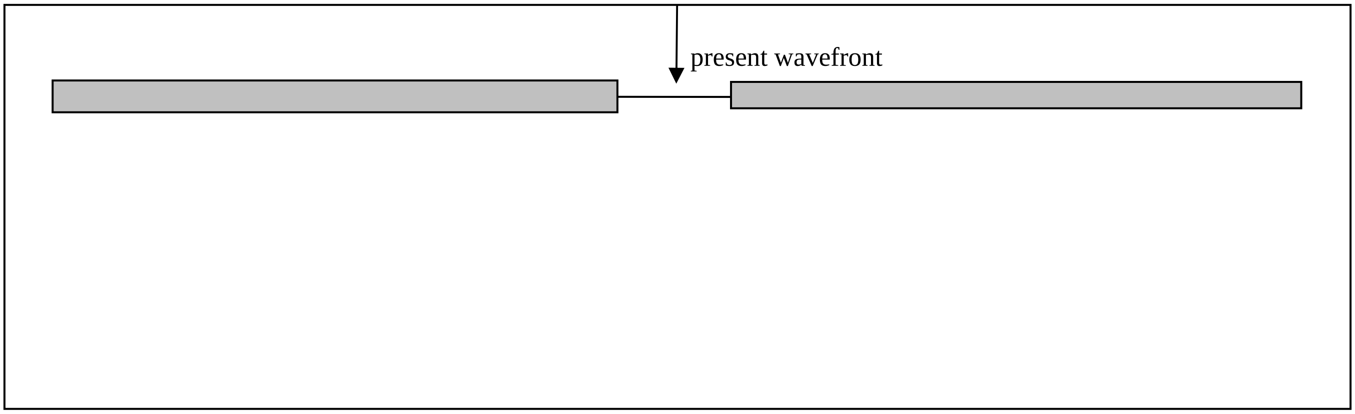


1. **Reason.** What does the radius of the penny represent about the wave?

2. **Represent.** We will use this technique to model what happens when a wave passes through the **wide** opening of your eye. 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 representing your eye when you squint. Find the next three wave fronts.



4. **Describe.** What happens to the shape of the original wavefront after it passes through an opening?

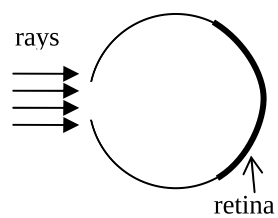
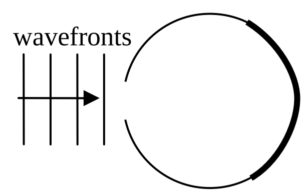
When a wave front changes shape as it travels through an opening or around a barrier we say it *diffracts*.

5. **Observe.** In which example above was the *diffraction* of the wave greatest (greatest change in shape)? Explain.

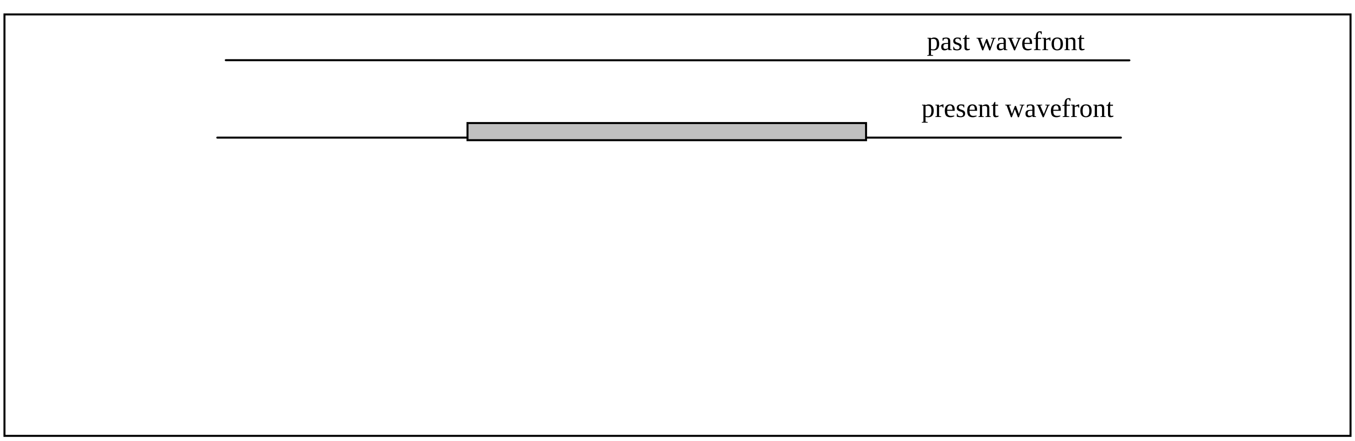
6. **Reason.** Compare the width of the opening with the wavelength. Speculate on the condition necessary for strong diffraction to occur.

7. **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.

8. **Evaluate.** Which theory best describes your observations in Part A? What are the limits of the theory of geometrical optics?

Geometrical Optics (light as rays)	**Wave Optics (light as wavefronts)**
	

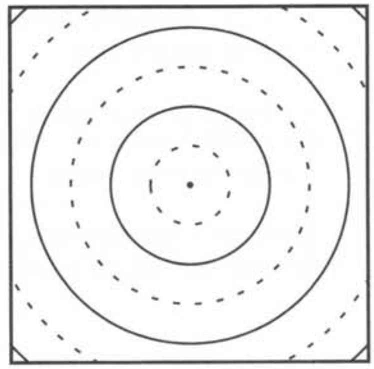
9. **Represent.** This is not related directly to the eye, but **w**hat happens when a wave meets an obstacle? In particular we want to study the region *behind* the obstacle. Find the next three wave fronts.



SPH4U: Two Source Interference

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

I. Periodic circular waves: single source



The circles at right represent wavefronts of a periodic circular wave in a portion of a ripple tank. The dark circles represent crests; the dashed circles, troughs. The diagram shows the locations of the wavefronts at one instant in time, as a photograph would.

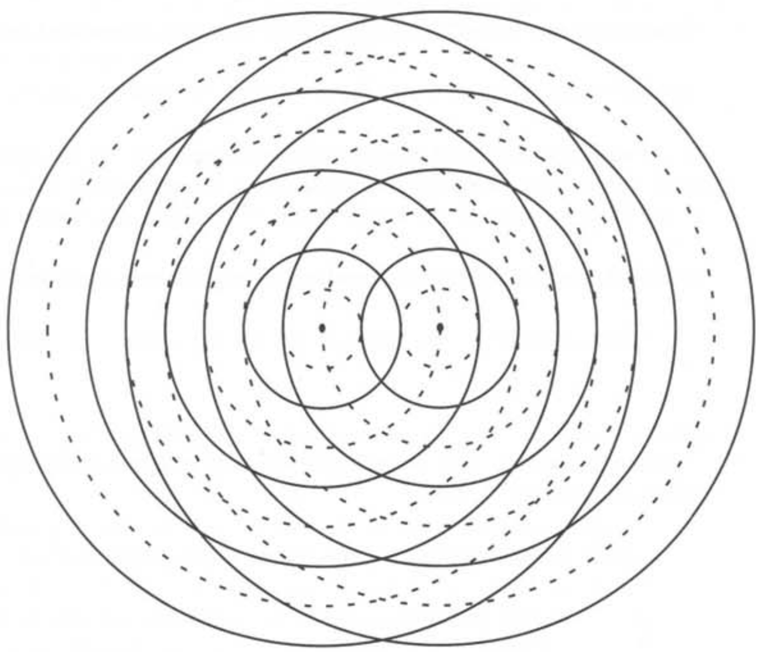
How, if at all, would the diagram differ:

- one-quarter period later? Explain.

- one period later? Explain.

II. Periodic circular waves: two sources

A. The diagram at right illustrates the wavefronts due to each of two small sources.



How do the frequencies of the two sources compare? Explain how you can tell from the diagram.

Are the two sources in phase or out of phase with respect to each other? Explain how you can tell from the diagram.

What is the source separation? Express your answer in terms of the wavelength.

B. Describe what happens at a point on the surface of the water where:

- a crest meets a crest
- a trough meets a trough
- a crest meets a trough

For each of the above cases, describe how your answer would differ if the amplitudes of the two waves were *not* equal. Explain your reasoning.

If the waves from two identical sources travel different distances to reach a particular point, the amplitudes of the waves from the two sources will not be the same at that point. For points that are sufficiently far from the sources, however, the difference in the amplitudes of the waves is small. For the remainder of this tutorial, we will *ignore* any such amplitude variations.

C. You have been provided a larger version of the diagram of the wavefronts due to two sources.

Use different symbols (or different colors) to mark the places at which *for the instant shown:*

- the displacement of the water surface is zero (*i.e.*, at its equilibrium level)
- the displacement of the water surface is the greatest above equilibrium
- the displacement of the water surface is the greatest below equilibrium

(*Hint:* Look for patterns that will help you identify these points.)

What patterns do you notice? Sketch the patterns on the diagram in part A.

D. The representation that we have been using indicates the shape of the water surface at one particular instant in time.

Consider a point on your diagram where a crest meets a crest.

How would the displacement of the water surface at this point change over time? (*e.g.*, What would the displacement be one-quarter period later? What would it be one-half period later?)

Consider what happens at a point on your diagram where a crest meets a trough.

How will the displacement of the water surface at this point change over time?

E. Suppose that a small piece of paper were floating on the surface of the water. Use your diagram to predict where the paper would move (1) the least and (2) the most.

F. Consider a point where the water surface remains undisturbed.

1. Explain why that point *cannot* be the same distance from the two sources that we are considering.

   For the two sources that we are considering, by how much must the distances from that point to the two sources differ?

      Is there more than one possible value for the difference in distances? If so, list the other possible value(s) for the difference in distances. Explain.

2. Choose a variety of points where the water surface remains undisturbed.

   For each of these points, determine the difference in distances from the point to the two sources. We will call this difference in distances ΔD. (This difference in distances is often called the *path length difference*.)

   Divide all of the points where the water surface remains undisturbed into groups that have the same value of ΔD. Label each group with the appropriate value of ΔD, in terms of the wavelength, λ.

   Justify the term *nodal lines* for groups of points that are far from the sources.

3. Similarly, group the points where there is maximum constructive interference according to their value of ΔD. We will call these *lines of maximum constructive interference*.

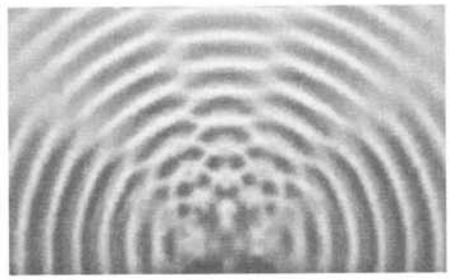
   Label each group with the appropriate value of ΔD, in terms of the wavelength, λ.

➪ Check your answers thus far with a tutorial instructor before continuing.

G. Imagine observing the waves from above the ripple tank. How, if at all, would the nodal lines and lines of maximum constructive interference change over time? Explain.

   What patterns and symmetries do you notice in the arrangement of the nodal lines and the lines of maximum constructive interference?

H. Each of the photographs at right shows a *part* of a ripple tank that contains two sources that are in phase.



For each of the photographs, identify:

- nodal lines
- the approximate locations of the sources
- the line that contains the two sources

Which of the two photographs more closely corresponds to the situation that you have been studying? Explain your reasoning.

What difference(s) in the two situations could account for the difference in the number and the locations of the nodal lines?

I. Obtain a piece of paper and a transparency with concentric circles on them. The circles represent wavefronts generated by each of two point sources.

Suppose that the two sources are in phase and at the same location. Overlay the transparency on the paper to model this situation.

Explain why there are *no* nodal lines in this case.

Gradually increase the source separation until you first see nodal lines.

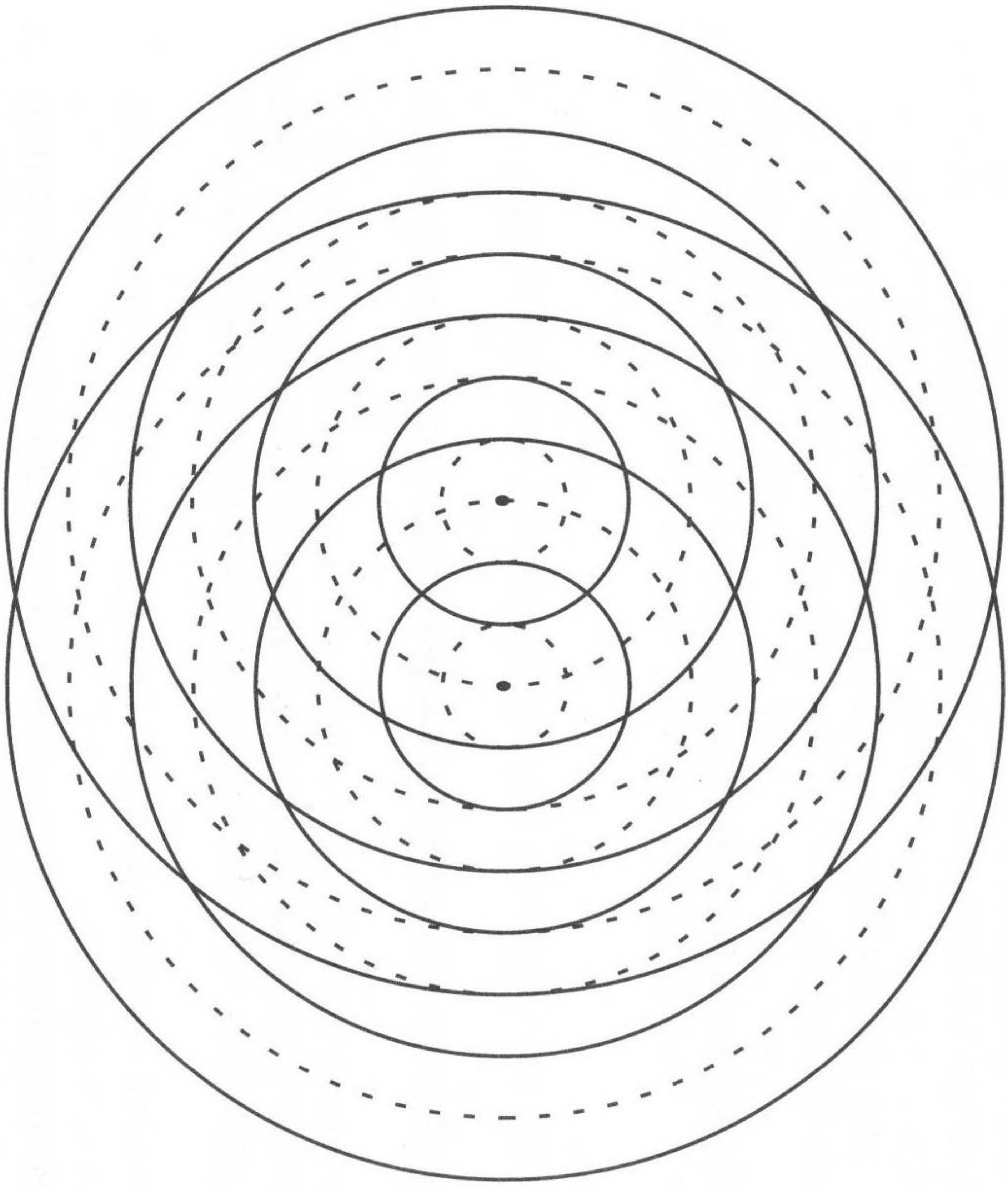
In the space at right, sketch the nodal lines and the lines of maximum constructive interference for this situation.

What is the source separation when this occurs?

Why can there be no nodal lines for a smaller source separation? Explain. *(Hint:* For a given source separation, what is the largest possible value of ΔD?)

Continue to increase the source separation and investigate how the source separation affects the number of nodal lines and their locations.

➪ Check your answers above with a tutorial instructor.

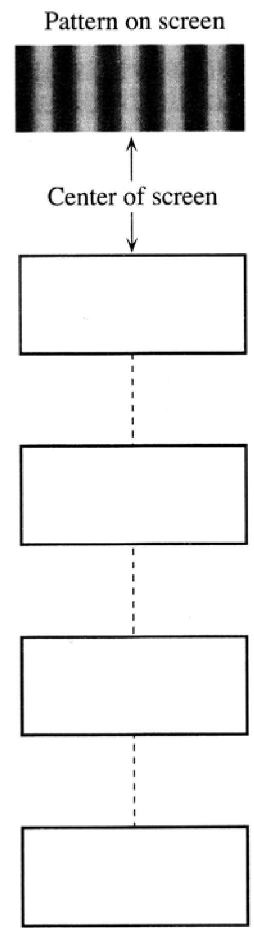


SPH4U: The Double-Slit Interference Pattern

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

E. The pattern produced by red light passing through two very narrow slits has been reproduced at right.

In each part below, suppose that a *single* change were made to the original apparatus. For each case, determine how, if at all, that change would affect the pattern on the screen. Sketch your predictions in the spaces provided.



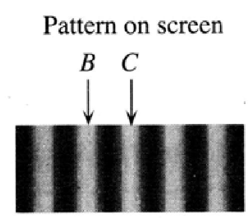
1. the distance between the slits is decreased (without changing the width of the slits)

2. the screen is moved closer to the mask containing the slits

3. the wavelength of the incident light is decreased

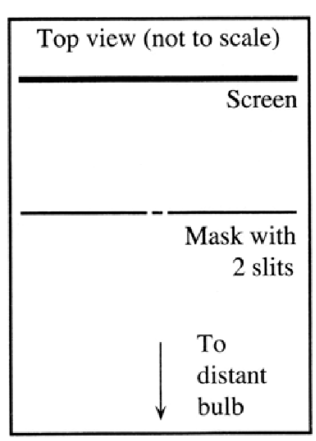
4. the width of each slit is decreased (without changing the distance between the slits)

F. Consider point *B*, the first maximum to the left of the center of the screen.



Suppose that the two slits are separated by 0.2 mm, that the screen is 1.2 m away from the slits, and that the distance from the center of the pattern (point *C*) to point *B* is 3.6 mm.

Use this information to determine the wavelength of the light. Describe any approximations that you make in answering this question.



from McDermott and Shaffer, *Tutorials in Introductory Physics.* Prentice Hall, 2002