Physics 20 & 30

Lab Manual

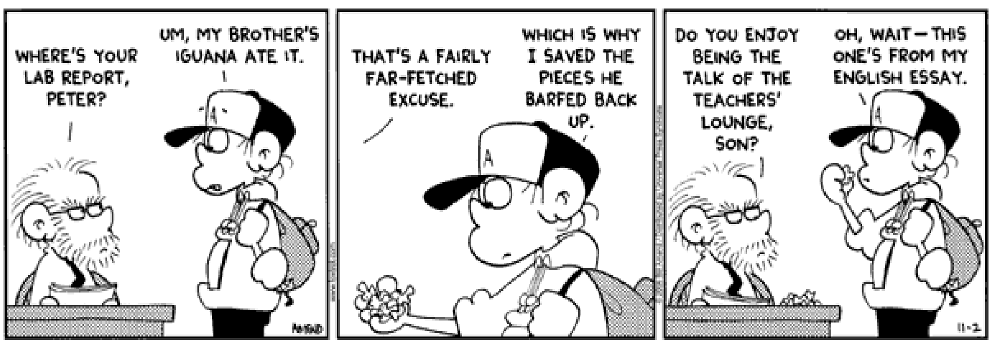

Table of Contents

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Introduction

The following lab manual includes labs to be performed by Physics 20 and 30 classes. Labs 1 to 11 are intended for Physics 20 students, and labs 12 to 23 are used in Physics 30. Some of the labs are meant to be done in a group, others are solo labs. Consult with your teacher in advance to make sure you know which are which. Some labs are referred to as “Gedanken Labs” where you run the lab in your mind based on known physics theories and data is supplied to you. Gedankens are sometimes necessary since it may be impossible or inconvenient (for various reasons) to actually perform the experiment. Many of these gedanken labs show several groups of available data (“Group Alpha”, “Group Beta”, etc.). Your teacher will assign you to use ***one*** of these data groups.

The goal of these labs is to show how the physics theories we study can be verified in real world situations. Although we fully expect our final conclusions to not exactly agree with theoretical values (due to sources of error), we always create a hypothesis based on a what **would** happen in an **ideal** world. In some labs, your hypothesis might include several possible outcomes. One of the greatest skills you can develop is to explain the sources of error that result in variations from perfect values.

Make sure that you look at all the Appendices at the end of this manual when you are preparing a lab report. They include specific information on...

- Laboratory Report Format (Appendix A)
- Marking Rubric (Appendix B)
- Error Calculation Formulas (Appendix C)
- Linear Regressions (Appendix D)
- General FAQ (Appendix E)

Always remember that the skills you develop in Physics 20 and 30 such as sig digs, linear regressions, and demonstrating methods of problem solving are critical to your success in performing these labs and writing the reports.

In the lab outlines given here you will not see all of the sections of the lab report you are expected to complete. This is because you only need to know about specific details for some of the sections of your lab. **Always write your lab report with ALL sections included, unless you are specifically told to ignore a section.**

Also keep in mind that all your basic physics rules such as significant digits and showing all your work must be followed as you work on writing your labs.

Physics 20 Labs

Lab 1: Velocity Gedanken Lab

Number of Students	Solo	Chapter	1: Kinematics	Marks	24

The *Never-Go* toy company has a problem. Customers are complaining that the *Roaring Roadster*® radio controlled toy car that *Never-Go* makes is not able to move fast enough when the speed is set at maximum. The packaging claims that it can move at over 35km/h.

Objective:
The company asks you, as an "independent laboratory," to figure out what the speed of the car is when it is set at maximum, and in the process either confirm or refute the customers' claims.

Hypothesis:
You must complete all three parts of the standard hypothesis. Make sure to take into account who you believe most, the company or the customers.

Equipment:
You are coming up with a make believe list of equipment you would have used, but still keep it reasonable… stuff you would actually be able to get in a high school or affordably from a store.

Procedure:
Your procedure must describe how you ***would have*** conducted your experiment with the car to get the observations.

Pre-Lab Questions:
None assigned.

Observations:
You take one of the cars and set the speed to maximum. You then collect data for how far it is able to travel (displacement) during several different time intervals. You will be assigned to use ***one*** of the groups of data below by your teacher. Be sure to indicate which group you belong to ***(e.g. Alpha) in the title of the lab.*** The table of given values is all you need for the Observations section.

Group Alpha

Trial	Time (s)	Displacement (m)
1	5.00	49.5
2	10.0	102
3	15.0	148
4	20.0	198
5	25.0	246

Group Beta

Trial	Time (s)	Displacement (m)
1	5.00	45.0
2	10.0	100
3	15.0	140
4	20.0	195
5	25.0	240

Group Gamma

Trial	Time (s)	Displacement (m)
1	5.00	40.0
2	10.0	95.0
3	15.0	130
4	20.0	188
5	25.0	230

Group Epsilon

Trial	Time (s)	Displacement (m)
1	5.00	42.0
2	10.0	100
3	15.0	137
4	20.0	198
5	25.0	240

Analysis:
In the **Analysis** section you will use a suitable averaging technique (see Appendix D) to create a **linear** graph based on the data. Think carefully about how to correctly place the variables on the x and y axis. You will then ***use your graph*** to get the average velocity of the car. You will get **no marks** for simply calculating the velocity five times using the formula v = d/t.

Error:
When you are completing the **Error** section, make sure to compare your experimental value to the company's accepted value for the speed of the car. You must also calculate your error using an appropriate method.

Conclusion:
In addition to everything else, your conclusion must contain a statement as to whether or not the company is in trouble with their customers.

Post-Lab Questions:
None assigned.

Lab 2: Acceleration Gedanken

Number of Students	Solo	Chapter	1: Kinematics	Marks	24

This lab is done as a replacement for the Velocity Gedanken Lab for students in special situations, such as joining a Physics 20 class late, after the Velocity Gedanken Lab was completed. The majority of Physics 20 students will not complete this lab. You must have permission from your teacher to do this lab.

As part of the last day of classes festivities, a Physics 20 class decided to put water balloons to good use and find an experimental value for the acceleration due to gravity. They set up a measurement scale along the outside of the school, and drop water balloons from the roof while someone takes a series of pictures with a camera set at 0.10 s intervals.

The data that they collected follows.

Time (s)	**Displacement (m)**
0.10	0.040
0.20	0.20
0.30	0.43
0.40	0.78
0.50	1.22

Based on this information, you need to write up a full lab report to determine the acceleration due to gravity. You must keep the following in mind while writing up your lab report.

- You must write a complete lab report following all the guidelines.
- Your **Procedure** must describe the detailed explanation of how you would have conducted your experiment with the water balloons to get the data above.
- The table above is all you need for the **Observations** section.
- In the **Analysis** section you will use a suitable averaging technique (see Appendix C) to create a **linear** graph based on the data. Think carefully about how to correctly place the variables on the x and y axis. You will then ***use your graph*** to get the rate of acceleration of the water balloons.
- When you are completing the "Sources of Error" section, make sure to compare your experimental value to the accepted value for the acceleration due to gravity.

Lab 3: Equilibrium of Forces Lab

Number of Students	Two to Four	Chapter	2: Vectors	Marks	28

Equilibrium of forces happens when a set of vectors "cancel" each other out resulting in zero net force. There are many examples of equilibrium of forces in daily life, such as a book resting on a table. In that situation you could say that the force of gravity and the normal force are in a state of equilibrium. If one vector cancels out the effect of other vectors, that one vector is an ***equilibrant***. An equilibrant is the exact opposite idea of a resultant.

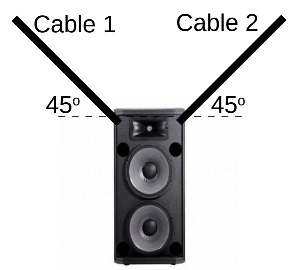
Objective:
The goal of this lab is to determine if a state of equilibrium that exists in a real world, measured, two-dimensional force-vector system agrees with theoretical predictions.

Hypothesis:
Usually we focus on the physics formulas and skip mentioning the math formulas, but this lab is an exception. Go ahead and list the math formulas you will use in your analysis. You can skip mentioning the control/manipulated/responding variables.

Equipment:
You will be using three spring scales calibrated to show force in Newtons. Make sure to read the force shown in Newtons, not the mass in grams.

Procedure:
You will be pulling the springs in three different directions while they are attached to each other, making a "Y" shape. You will be doing this over a sheet of paper so that you can quickly draw vectors for each scale, showing their directions and magnitudes of forces.

Pre-Lab Question:
A real world example of equilibrium of forces similar to this lab involves using cables to suspend the large speakers used at concerts from the ceiling. The diagram to the right shows such a situation. Based on this diagram, **sketch** a free body diagram of the forces acting on the speaker. Then **sketch** how these vectors add up to show equilibrium.



Observations:
You will need to set up ***one*** reference line on your big sheet to do your measurements from. This can be done by simply laying a metre stick across the page and drawing a single line. Measure all your vectors angles from this one reference line. This is NOT considered your final observations. You will need to create a table of values in your lab write up that shows all information about the vectors. You must still hand in the big sheet of paper so it can be double checked as needed. Make sure all members of your group put their names on it.

Analysis:
If you do any calculations on the big sheet of paper, please keep in mind that it is considered rough work and will not be marked. You must include redrawn vector diagrams in your lab report showing all your calculations clearly.

In your analysis you will randomly choose **two** of the vectors and determine their x and y components. Based on these values you can determine what the ***predicted*** components of the equilibrant (the third vector) should be. You will then determine the ***actual*** x and y components of the third vector. You are hoping that the ***predicted*** and ***actual*** components will be about the same.

Error:
You must determine two errors, one for the x component and one for the y component.

Conclusion:
Make sure to point out if, within reasonable error, equilibrium happened.

Post-Lab Question:
You had to calculate two error values for this lab. **Explain** why having two calculations for error could be a problem for coming to a conclusion regarding the success or failure of your lab.

Lab 4: Horizontal Projectile Motion Lab

Number of Students	Two to Four	Chapter	2: Vectors	Marks	28

Objective:
To find if the model for horizontal projectile motion shows the same horizontal component of an object's velocity as predicted using other methods.

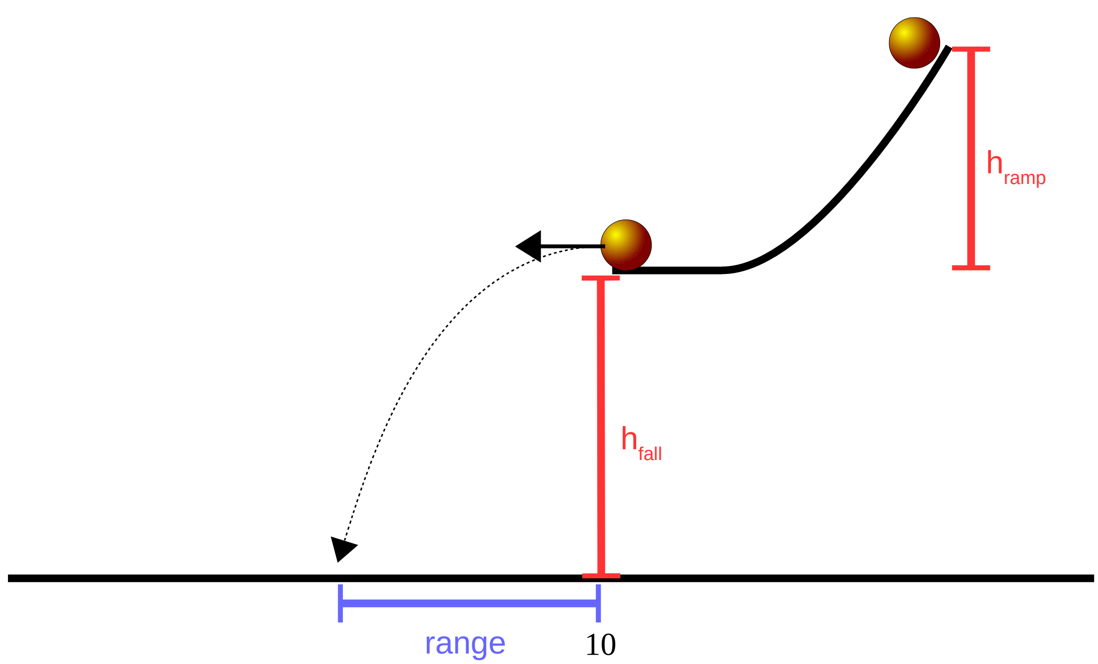
Equipment & Procedure:
A special ramp will be used that allows you to roll a metal ball from a known height so that when the ball leaves the ramp it will be traveling at a horizontal velocity you can calculate. The ball will then be allowed to fall in projectile motion.

Pre-Lab Question:
1. **Identify** the major physics principle that you use in order to calculate the velocity of the ball as it leaves the ramp after rolling down from the top. *This is not projectile motion we are talking about.* **Explain** what you are ignoring that could affect your answer.
2. **Explain** how you will choose between using percent error or percent difference in the error section of this lab.

Analysis:
You are going to use two totally different methods to determine the horizontal velocity of the ball as it leaves the bottom of the ramp. In a perfect world, your values for the horizontal velocity would be identical.

- You can determine the horizontal velocity as the ball leaves the bottom of the ramp by knowing how high up it started on the ramp. This is based on the major physics principle you identified in the first pre-lab question.
- When the ball leaves the ramp and follows projectile motion, you can measure the ball's range. You can determine the horizontal velocity that the ball must have had to be able to move that range.

Error:
Compare the two measurements of horizontal velocity and see how close they are to each other.



Lab 5: Buoyancy of a Wooden Block

Number of Students	Two to Four	Chapter	3: Forces	Marks	30

Archimedes is remembered for his method to measure the volume of a golden crown made for King Hiero II, known today as Archimedes' Principle. You might have heard the part of the story about Archimedes running naked through the street yelling "Eureka" (Greek for "I have found it").

Objective:
To measure the volume of a wooden block.

Hypothesis:
Archimedes' Principle states that the force of buoyancy that an object experiences is equal in magnitude to the weight of the water that the object displaces. If an object floats while entirely submerged, the object is displacing a volume of water equal to the object's volume. The buoyancy caused by this can be calculated using the formula

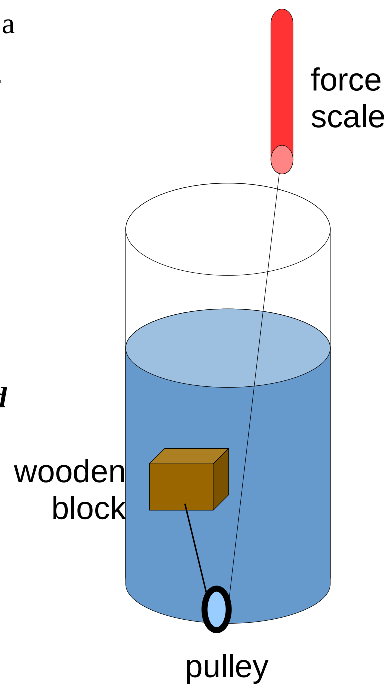
$$F_B = \rho_{water} V_{sub}\, g$$

F_B = force of buoyancy (N)
ρ_{water} = density of water (1.000e3 kg/m^3)
V_{sub} = volume of object submerged (m^3)
g = acceleration due to gravity (m/s^2)

You are **not** required to list your manipulated, responding, and controlled variables.

Equipment & Procedure:
In order to hold your block completely under water, you will be pulling on a string that goes through a hook on the bottom of the container. One end of the string is attached to the bottom of the block, while the other end (out of the water) is attached to your force scale.

Pull on the scale enough that the block is completely under water and motionless. Read the force you are applying on the force scale.



Pre-Lab Questions:
1. Carefully measure the length, width, and height of your wooden block. Use this data to **determine** the accepted volume of your wooden block. ***This value should be stated in your hypothesis and will be treated as your "accepted" value.***
2. Carefully measure the mass of your wooden block.
3. **Sketch** a free body diagram of your block motionless under water. This diagram represents what is happening while you are pulling down on the block. Make sure to include all forces.

Analysis:
Using your free body diagram to determine how the forces are related, figure out the force of buoyancy acting on the block. Then, you should be able to determine an experimental value for the volume of the block.

Lab 6: Coefficient of Friction

Number of Students	Two to Four	Chapter	3: Forces	Marks	26

Objective:
To measure the kinetic coefficient of friction between two surfaces.

Equipment:

- spring scale
- digital scale
- at least three random objects of known mass
- wooden block (of known mass) with hook
- flat surface (such as a table top)

Procedure:
Make sure that you measure the mass of each of the objects using the digital scale supplied to you. Now attach the spring scale to the wooden block and place the first object on top. Pull it horizontally along the surface at a constant velocity. While doing this read the amount of force you are applying to the block. Now add the second object on top and repeat pulling it across the surface. Finally, add the third object on top and pull across the surface again. Remember to record the force you exerted in each trial.

Pre Lab Questions:

1. **Sketch** a free body diagram of the mass being dragged across the surface.
2. From your free body diagram, **identify** which forces are equivalent to each other (even if they are in different directions).

Analysis:
You will use a suitable averaging technique to create a **linear** graph based on the data. By analyzing your graph, determine the value of the coefficient of sliding friction for your surfaces.

Error:
You will not be able to calculate an error in this lab. You still need to mention sources of error.

Lab 7: Elevator Lab

Number of Students	Two to Four	Chapter	4: Gravity	Marks	24

The acceleration of elevators as they move up or go down is very important to the designers of elevators: people want to be able to travel on the elevators as quickly as possible, but if the elevator accelerates too much they will feel sick.

Objective:

To measure the acceleration of an actual elevator as it rises and as it descends (most often these will be two different values).

Procedure:

You are responsible for coming up with a procedure that will work. Consider the following as you perform the lab.

1. Acceleration only happens at the start and end of your trip. During the middle of your trip you will be traveling at a fairly constant velocity.
2. We want two separate accelerations to be measured...
    - one as the elevator starts to go up and you feel heavier.
    - the other as the elevator starts to come down and you feel lighter.
3. Choose an elevator that travels quite a distance (a lot of floors). Probably an elevator in a tall office building or apartment building will work best.
4. Make sure that your parents/guardians know where you are going and what you are doing… you might even want to invite them along (they could be your "test mass")
5. If you are in a building that has an information desk, security, etc. ask for permission before you do the experiment. I'm sure that if you explain to the person that you are doing this for a physics lab, and that you will not ride up and down on the elevator more than necessary, they will be ok with you doing it. Probably about three measurements will be enough.
6. Bring a regular bathroom scale with you. An old dial one works much better than a digital one. Find your mass before getting onto the elevator. Then get in the elevator, and while standing on the scale, go up and down. Record your maximum/minimum mass as shown on the scale while you are accelerating.

Analysis:

Based on the example we did in the notes for elevators, you should be able to see a way to use your mass measurements to calculate the acceleration of the elevator.

Error:

Although you can still mention sources of error for this lab, you will not calculate a percent error.

Lab 8: Exoplanet Gedanken

Number of Students	Solo	Chapter	5: Circular Motion	Marks	18

An ***extrasolar*** planet, or ***exoplanet***, is a planet beyond our own Solar System that orbits a completely different star. As of June 17, 2014, 1732 exoplanets have been confirmed by scientists. Although most of these exoplanets can not be visually seen, scientists can observe the effects they have on the stars they orbit. For example, since most of the exoplanets are huge (about the size of Jupiter) it is possible to see the star they orbit wobble. Through careful observation of the wobble, it is possible to predict the relative size and distance of the planets orbiting the star.

For more information...
...about Extrasolar Planetary Systems, visit NASA's Jet Propulsion Laboratory website "PlanetQuest."

Objective:
You will determine if the unconfirmed planet shown last on your list ***could*** be an exoplanet in that solar system.

Hypothesis:
When you do your hypothesis you do NOT need to list manipulated, responding, and controlled variables.

Equipment & Procedure:
Your lab write up will ***not*** have an equipment list or procedure. The technology and equipment used to collect the data shown here is beyond the scope of Physics 20. Just make a "not available" note in those two sections.

Observations:
You will use one of the data sets shown (check with your teacher). Please note that the names of exoplanets are based on the name of the star they orbit followed by a letter (like "b"). You are working on a team that is trying to analyze this data. You are lucky that there are several planets that have been confirmed for your extrasolar planetary system, since more data increases your accuracy. The last planet marked with * is the unconfirmed planet you are trying to verify.

Group Alpha: 55 Cancri

Exoplanet	Period of Orbit (d)	Mean Orbital Radius (AU)
55 Cancri b	14.66	0.118
55 Cancri c	44.28	0.240
55 Cancri d	5360	5.90
55 Cancri e	3.00	0.0400
55 Cancri f	260.8	0.738
55 Cancri g*	24.0	0.190

Group Beta: Mu Arae

Exoplanet	Period of Orbit (d)	Mean Orbital Radius (AU)
Mu Arae b	643.25	1.497
Mu Arae c	9.6386	0.09094
Mu Arae d	310.55	0.921
Mu Arae e	4205.8	5.235
Mu Arae f*	2301.4	3.478

* Unconfirmed Planet

Group Gamma: Gilese

Exoplanet	Period of Orbit (d)	Mean Orbital Radius (AU)
Gilese 876 b	61.116	0.208
Gilese 876 c	30.008	0.130
Gilese 876 d	1.938	0.0208
Gilese 876 e	124.26	0.334
Gilese 876 f*	604.01	0.955

Group Epsilon: Upsilon Andromedae

Exoplanet	Period of Orbit (d)	Mean Orbital Radius (AU)
Upsilon A b	4.6171	0.0595
Upsilon A c	241.33	0.832
Upsilon A d	1278.1	2.53
Upsilon A e	3848.9	5.2456
Upsilon A f*	1001.5	1.887

* Unconfirmed Planet

Analysis:
You will use a suitable averaging technique to create a **linear** graph based on the data for the ***confirmed planets***. You must make sure that you have adjusted the original data so that you have a linear relationship. You will then ***use your graph*** to calculate a value important in the study of planets' orbits. As its own separate calculation, you will also need to calculate that same important value for your ***unconfirmed planet***.

Error:
Make sure to calculate a percent error that allows you to compare ***the confirmed exoplanets as one group*** to the value you have for the ***unconfirmed planet***. You do **not** need to list sources of error for this lab.

Conclusion:
Your conclusion must contain a statement as to whether or not the unconfirmed planet could possibly be an exoplanet in this extrasolar system.

Lab 9: Hooke's Law

Number of Students	Two to Four	Chapter	6: Energy	Marks	24

Objective:
To measure the spring constant of a spring.

Equipment:

- spring scale
- digital scale
- at least three objects with known mass
- ruler

Procedure:
Make sure that you measure the mass of each of the objects using the digital scale supplied to you. Next, hold the spring scale vertically and temporarily mark the equilibrium point of the scale with a piece of tape. Then hang each of the masses from the scale, one at a time, while recording the ***deformation*** of the spring each time with the ruler.

Analysis:
You will use a suitable averaging technique to create a linear graph based on the data you collected. By analyzing your graph, **determine** the value of the spring constant.

Error:
In order to state your hypothesis and calculate your error, you will need these accepted values for the spring constant for each of the scales...

Scale	**k (N/m)**
Brown Plastic	**161**
Green Plastic	**98.0**
Red Plastic	**385**
Red Metal	**299**

Make sure you identify the scale that you used correctly.

Lab 10: Measuring Gravity with a Pendulum

Number of Students	Two to Four	Chapter	7: Simple Harmonic Motion	Marks	24

The accepted value for gravity that is found on your data sheet (9.81 m/s^2) is actually the average across Alberta. The true value of the acceleration due to gravity varies from place to place. Although the value does not change very much (you won't "feel" heavier in Calgary and lighter in Grand Prairie), the differences are measurable and important when performing delicate physics experiments.

Objective:
The purpose of this lab is to measure the acceleration of gravity in Edmonton.

Hypothesis:
For this lab you will still treat 9.81 m/s^2 as the accepted value for gravity.

Procedure:
To measure gravity, you will use a simple pendulum (made out of thread and a weight tied to the end). There are a few things to consider when you come up with your procedure for this lab:

- This formula is only reliable and accurate for angles of at most about 15° away from the equilibrium point.
- You **MUST** do the lab using several different length pendulums. I would suggest that you do at least five different lengths, and try to do about three trials for each length. That's a total of at least 15 trials. You should have an observations table that shows at least 15 separate trials.
- It is quite difficult to measure the exact period of just one swing, so come up with a method that will still let you know the time for one swing. *Hint: If I asked you to measure the thickness of a piece of paper, you would measure the thickness of, say, 100 pages in a book, and then divide that number by 100.*

Pre-Lab Questions:
1. Just as an example, while doing one of your trials you let the pendulum swing back and forth five complete swings while using your stopwatch to time it. **Explain** if you just recorded the *time* or *period*.

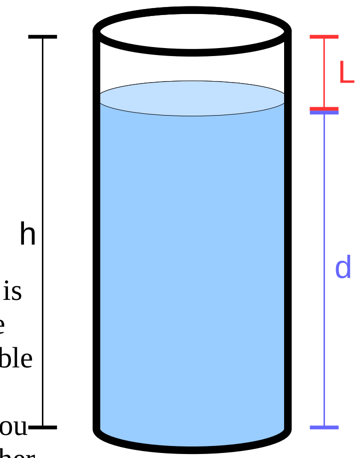
Analysis:
You will use a suitable averaging technique to create a **linear** graph based on the data. This will allow you to determine the value of gravity.

Post-Lab Questions:
1. If Galileo tried to do this same lab in his time, explain what major difficulty he would have had performing the experiment.
2. If you did this same lab on the moon, explain how your observations would be different.

Lab 11: Speed of Sound

Number of Students	Two to Four	Chapter	8: Waves	Marks	26

A tuning fork held above a closed end pipe of the correct length will cause the sound to resonate and become louder. This will only happen at exact multiples of the harmonic length of the tube.



Objective:
To measure the speed of sound.

Hypothesis:
Although the speed of sound varies slightly with temperature, you will assume an accepted value of 340 m/s.

Procedure:
You will be given a graduated cylinder to act as your closed ended pipe. The problem is that the graduated cylinder will be a random **height** that is not able to cause resonance with your tuning fork. By slowly filling it with water to various **depths**, you will be able to shorten the **length** of the air column until you reach a point where the length is the same as one of the harmonics of the tuning fork. This is when it will seem louder. If you continue filling it water, you should be able to find other lengths that correspond to other harmonics.

Pre-Lab Questions:

1. Assume that the speed of sound is 340 m/s. Based on the frequency of the tuning fork your group is using, **determine** the approximate **length** of the air column for the first, third, and fifth harmonic. Show all your work here, and copy the answers into the appropriate spot in the table in the Observations section. You will use these values to know approximately what **depth** of water needs to be added to your tube.

Observations:
Don't forget to record your tuning fork's frequency.

Harmonic	**First**	**Third**	**Fifth**
Predicted Length (m)			
Actual Length (m)			

Analysis:
Based on your three trials data, determine the average speed of sound.

Physics 30 Labs

Lab 12: Conservation of Momentum Lab

Number of Students	Two to Four	Chapter	9: Momentum	Marks	24

The purpose of this lab is to confirm if the law of conservation of momentum applies to 1-D and 2-D collisions. Throughout the lab, keep in mind that you are ***not*** solving for any unknown; you will know all the masses and all the velocities, and therefore all the momentums. What we want to examine is whether or not the total initial momentum you measure at the start is the same as the total final momentum at the end. Also consider that although your final results will not have a 0% error (that would be exceedingly rare!) you must make a ***reasonable*** judgment as to whether or not conservation of momentum applied in your collisions.

Objective:

To determine if momentum is conserved during 1-D and 2-D collisions.

Equipment:

The following is a list of the equipment you will be using for the lab. Please ensure that you pay very careful attention to the instructions you are given. Although the risk is minimal, this equipment does use an electric spark generator; ***failure to follow safety instructions could result in electrocution of yourself and others, as well as damage to the equipment***.

- **Air Table**: make sure that you do not bump or lean on the table, as it is very easily moved. It has been levelled out for you before you begin.
- **Air Compressor**: The compressor is adjusted to the correct output for your lab. Do not try to adjust it.
- **Spark Generator**: The spark generator will only fire while the foot peddle is pressed. It is the most important (and most dangerous) part of the equipment. Make sure that everyone in your group has removed all electronic devices (watches, cell phones, iPods, etc) and wallets containing bank or credit cards from their pockets before coming up to the equipment. One person in your group will be responsible for the peddle that controls the generator. The peddle should only be pressed while the pucks are in motion. It will deliver one spark each 1/10 of a second through a wire in the puck to cause a small mark on the *underside* of the paper.
- **Pucks**: The pucks can be considered to be identical to each other in every way. You may use a mass of 505g for the purposes of your calculations.

Procedure, Analysis, and Error:

You will be doing two separate trials. In **Trial 1**, you will have one of the pucks motionless in the middle of the air table and hit it with the other puck in a head-on 1-D collision.

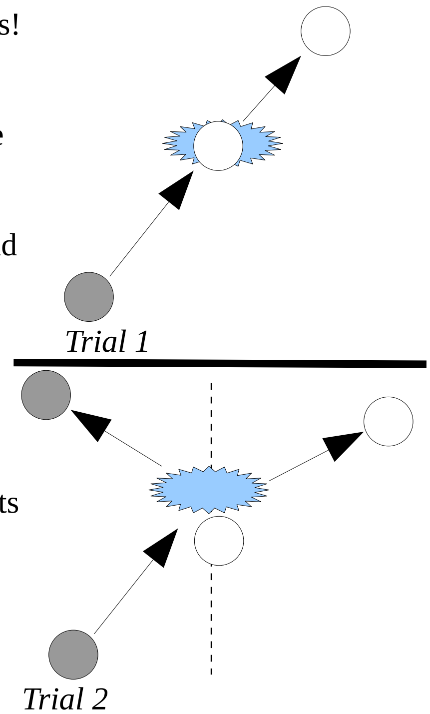
In **Trial 2** you will start again with one of the pucks motionless in the middle of the air table, but this time it will be hit by the other puck in a glancing 2-D collision.

Remember that this lab is fundamentally different from many of the questions you have been working on for conservation of momentum. Up until now, you have most often used the conservation of momentum in a situation where you have two objects colliding, but have had no knowledge of one of the objects motion at a particular time. You then used conservation of momentum to calculate that missing motion. ***This is not the case in this lab!!!***

In this lab, you have all the information about all the motion of all the objects!

Since you know...

1. the time (from how many spark dots are made)
2. the displacement (from measuring the distance covered by the spark dots)
3. the momentum (p = mv)
4. even the direction (measured from your own reference line and only applies to Trial 2)



...it may seem like you have nothing to calculate. That is not the case. What you need to remember is that you are trying to ***confirm*** the conservation of momentum. To confirm it, you will need to be able to show (***within a reasonable error***) that the momentum before the collision is equal to the momentum after. You can do this by figuring out the total x and y components before and after the collision and comparing them. To do this comparison, you will need to use a percent difference calculation...

$$Percent\ Difference = \frac{Difference\ Between\ the\ Numbers}{Average\ of\ the\ Numbers}$$

So, let's assume that you just finished Trial 2 of the lab. You took the distances and times to get velocity, then used that with mass to get momentum. You measured the angles and found all your components, adding them up to get x and y totals from before and after (note, I just told you how to do almost the entire analysis). You might have something that looks like this...

x total before = 17 kgm/s　　x total after = 14 kgm/s
y total before = 3 kgm/s　　y total after = 4 kgm/s

You will calculate the percent difference for the x totals...

$$Percent\ Difference = \frac{17-14}{\left(\frac{17+14}{2}\right)} = 0.19$$

...and the y totals...

$$Percent\ Difference = \frac{4-3}{\left(\frac{4+3}{2}\right)} = 0.29$$

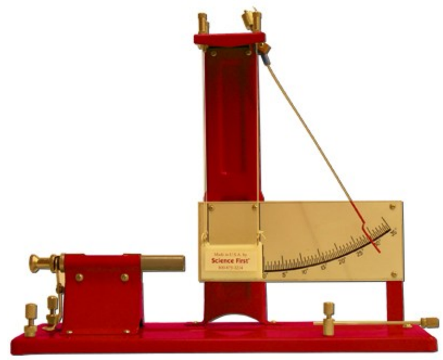
Giving you an overall error on that part of the lab of 24%. You would need to do this kind of work for Trial 1 of the lab as well.

Super Important Notes about the "Big Sheet"

- You must hand in your big sheet when you submit your lab report.
- Any work on the big sheet is considered rough work, not analysis.
- You must clearly write the names of all the group members on the big sheet.

Lab 13: Ballistic Pendulum Lab

Number of Students	Two to Four	Chapter	9: Momentum	Marks	26



One way to test the speed of a projectile is to use a device called a **ballistic pendulum**. Because it is based on well understood physics, it can give very accurate results even though the equipment is quite simple. A block of material is hung from supporting strings as shown at right. When the projectile is shot at the pendulum, it hits and becomes embedded in the pendulum. Together, the pendulum and the projectile swing upwards. By measuring the maximum height that the pendulum/projectile combination swing to, the speed of the projectile just before impact can be calculated.

Objective:
Determine the velocity of the projectile for each of the three notch settings.

Equipment:
Ballistic pendulum device
Metal ball projectile

> Note:
> m_{pend} = 80.00 g
> m_{ball} = 7.64 g
> length of string = 21 cm

Procedure:
The spring loaded launcher can be set to three different notches, corresponding to three distinct velocities. Perform at least three trials at each setting.

1. Ensure that the device is balanced so that the ball will shoot directly into the pendulum.
2. With the pendulum motionless, the red bar should be gently touching against the back of the pendulum.
3. Pull back on the launcher (like a pinball machine) so that it locks into one of the grooves.
4. Insert the ball in the front of the launcher... it will ***not*** go all the way in.
5. Push the launcher release lever (the thumb release is near the base).
6. Measure the angle that the red bar shows.
7. Repeat for several trials at each of the notch settings.

Post-Lab Question:
1. **Explain** how it would be possible to measure the value of the spring constant, “k”, using data collected in this lab. **Identify** the additional measurement you would need to take during the lab in order to succeed.

Lab 14: Electrostatic Gedanken Lab

Number of Students	Solo	Chapter	10: Electrostatics	Marks	26

You decide to perform a variation of Coulomb's experiment. Your purpose is to measure the unknown charge on a pith ball. The pith ball will be hanging in a spring loaded device so that it is near a metal sphere with a known charge. As the two are put at different distances from each other, the force acting on the pith ball can be measured with the spring device.

Objective:

Determine the charge on the pith ball.

Equipment:

The following is a list of the equipment for the lab.

- **Pith Ball**: These low-mass balls are made out of Styrofoam sprayed with a metallic paint covering. The metallic particles in the paint allow the charge to spread more evenly over the surface of the pith ball. Their low mass allows them to be easily moved around be even small forces.
- **Metal Sphere**: This object has been charged with a -3.59e-7 C charge.
- **Spring Device**: Measures force acting between the two spheres (don't worry how it works).

Observations:

There are four sets of quantitative data for this lab. You will be assigned to use the data from ONE of these groups.

Qualitative

It was noticed during the experiment that the objects attracted each other.

Quantitative

Group Alpha

Trial	r (m)	F_e (N)
1	0.050	0.58
2	0.10	0.14
3	0.15	0.070
4	0.20	0.040
5	0.25	0.020
6	0.30	0.015

Group Beta

Trial	r (m)	F_e (N)
1	0.050	0.32
2	0.10	0.080
3	0.15	0.035
4	0.20	0.020
5	0.25	0.010
6	0.30	0.0090

Group Gamma

Trial	r (m)	F_e (N)
1	0.050	0.81
2	0.10	0.21
3	0.15	0.090
4	0.20	0.050
5	0.25	0.033
6	0.30	0.024

Group Epsilon

Trial	r (m)	F_e (N)
1	0.050	0.44
2	0.10	0.11
3	0.15	0.050
4	0.20	0.030
5	0.25	0.016
6	0.30	0.011

Analysis:

Use an appropriate line straightening technique to determine the charge on the pith ball. It is necessary to make a graph in order to do this!

Error:

You will ***not*** be able to determine a percent error for this lab, since you have no way of confirming the actual charge on the pith balls. You must still mention sources of error that may have occurred while performing the experiment.

Post-Lab Question:

Explain why it is not necessary to take the force of gravity into account while performing this experiment.

Lab 15: Electric Fields and Charge-to-Mass Ratio Gedanken Lab

Number of Students	Solo	Chapter	11: Fields	Marks	30

You are going in to the lab today to use an electric field to determine the identity of an unknown charged particle. The source of the charged particle is a sample of a radioactive isotope. It will emit a constant stream of one type of particle. The only particles you are responsible for knowing about are the particles listed on your data sheet.

Hypothesis:

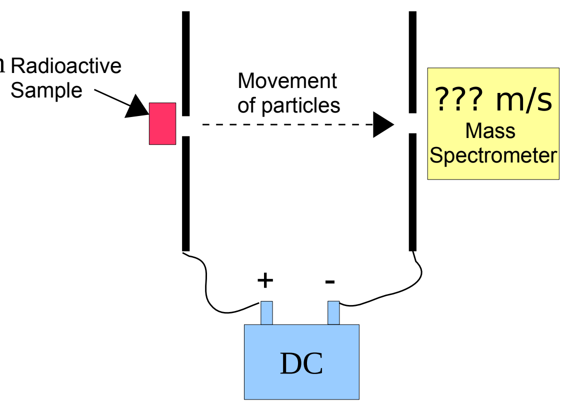
Your particle will be one of the basic ones from your data sheet. You will be identifying it based on its charge-to-mass ratio. Charge-to-Mass ratio is simply the value you get by taking the charge of a particle (q) and dividing by its mass (m). The answer is measured in C/kg . The true charge-to-mass ratios for the particles on the data sheet can be calculated from the values on the data sheet and used for comparison to your experimental value later on (you will do this calculation in your pre-lab questions).

There are ***two*** physics formulas that form the basis of this lab. Consider this; you will be observing the final velocity of the charged particle as it exits an electric field created by a voltage between two plates.

Equipment:

You will be given a set of parallel plates with a variable DC source in order to produce an electric field. There are holes drilled through both plates, so that the charged particles can enter and leave the space between the plates. All you need to do is place the radioactive sample at one of the holes. You will assume that the particles enter the field at a velocity close to zero.

On the far side, as the particle leaves the plates, it will enter a mass spectrometer which has been arranged to tell you the velocity of the particle. You do not need to know how this operates. It simply shows a velocity on a digital display.



Pre-Lab Questions:

1. Determine the theoretical values of the charge-to-mass ratio for electrons, protons, and alpha particles.
2. The plates are bolted into position 1.5 cm from each other. You will be adjusting your DC source to various voltages, starting with 10 V, 15 V, and 20 V. Determine the electric field between the plates at each of these settings.
3. As a “what-if” scenario, let's say you start up the apparatus as shown above to take your first measurement. The display on the mass spectrometer shows “???”. Your lab assistant tells you that it means ***no*** particles are reaching the mass spectrometer. What would you need to change in your setup, and why?

Observations:

Group Alpha

Qualitative

The initial setup worked just fine as shown in the diagram. Particles did reach the mass spectrometer at the velocities shown on the table.

Quantitative

Trial	V (V)	v (x10^4m/s)
1	10	2.9
2	15	3.6
3	20	4.4
4	25	4.6
5	30	5.2
6	35	5.8
7	40	6.3
8	45	6.5
9	50	7.0
10	55	7.1
11	60	7.5
12	65	7.8
13	70	8.4
14	75	8.6

Group Beta

Qualitative

The initial setup did not work as shown in the diagram. Particles did not reach the mass Spectrometer until you made changes.

Quantitative

Trial	V(V)	v (x10^4m/s)
1	10	4.5
2	15	5.5
3	20	6.3
4	25	7.1
5	30	7.7
6	35	8.9
7	40	9.0
8	45	9.6
9	50	9.7
10	55	10.3
11	60	10.7
12	65	11.1
13	70	11.6
14	75	12.0

Analysis:

Use an appropriate line straightening technique to determine the charge-to-mass ratio of the particle. This will allow you to identify the particle.

Error:

Once you have identified your particle in the analysis, compare your charge-to-mass ratio to the accepted value in this section.

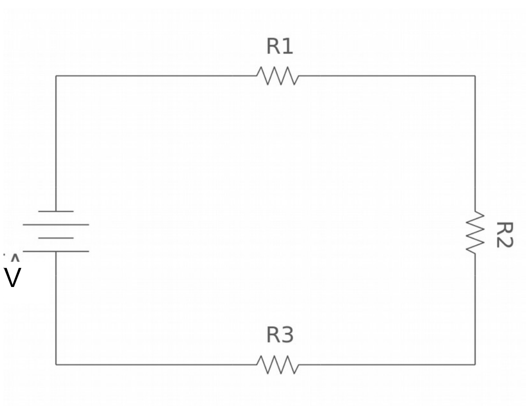
Lab 16: Breadboard Lab (AP Only)

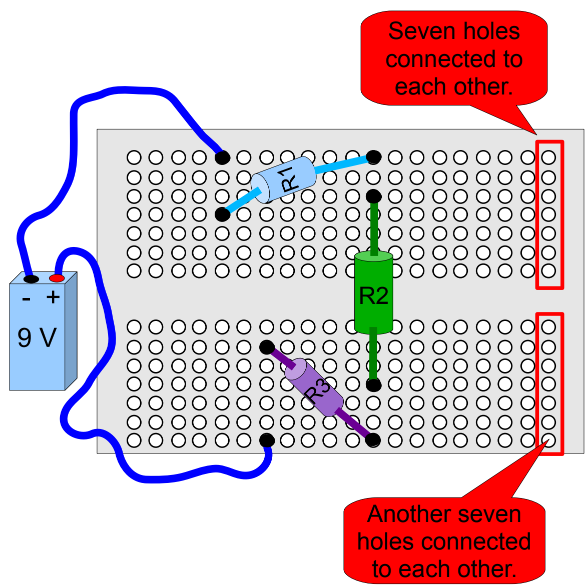
Number of Students	Two to Four	Chapter	Circuits	Marks	24

Lab Background

In order to really appreciate simple circuits, it is necessary to build them. Simply looking at schematics does not really let a student understand what is happening. In order to make make building simple circuits quick and easy, we can use **breadboards**.

A breadboard is a plastic tray with hundreds of little holes in it (looks kind of like a cribbage board). Underneath are metal spring clips that will grab wires that are pushed into the holes. These spring clips are attached to each other with either strips of metal or wires. In the diagram below, the top seven holes in one column are attached to each other, as are the seven holes in the bottom part. so that connections are made between adjoining vertical holes. The gap in the middle is where no holes are connected to each other.





Notice how the only connections that actually matter are the ones between the vertical holes, either along the top or bottom. *Connections do not happen horizontally*.

Objective:

Determine the voltage and current in all sections of a circuit.

Equipment:

- Breadboard
- Breadboard wires
- Alligator clips
- Battery
- Various resistors
- Multimeter

Procedure:

Select three random resistors. They should all be similar resistances, but do not have to be exactly the same. Sketch two schematics; one with them arranged in series, the other in parallel. Based on your schematics, predict the current and voltage drops in all parts of the circuit. Construct each circuit (one at a time). After building, test all parts of the circuit using the multimeter to measure the values of current and voltage drops.

Lab 17: Electromagnet Lab

Number of Students	Two	Chapter	12: Magnetism	Marks	36

The following is a general outline for your electromagnet project. If you believe that you need to deviate from these guidelines, please check it out with me first.

Objective:
Construct a working electromagnet capable of picking up various iron objects, ranging from paper clips to an iron rod.

Equipment:
Look around your house or do a quick visit to “Home Depot.” Please do not feel obligated to spend $50 on this…it ain’t worth it!

- Length of wire no greater than 15m
- Iron core (e.g. an iron nail)
- Self contained power source (e.g. 9 volt battery)
- *Optional* → some sort of switch mechanism to turn it off and on… if there is no switch, I must be able to connect/disconnect the wire from the battery in some way.

Procedure:
Construct the electromagnet based on what you learned in this section. It should be small enough to be easily transported, and able to pick up a bunch of paper clips. Your mark for the electromagnet itself will be based on following directions, effective use of materials, strength of electromagnet, and creativity, so keep this in mind while you design it. Use your imagination… make it interesting for me when I open the box!

Since you are dealing with electricity, make sure that you are careful not to cause yourself (or anyone else) any injury. Keep in mind that…

1. All batteries you give to me must be safe. **No leaking batteries, car batteries, shorted out cell phone batteries, etc. will be accepted**.
2. At no time will your design need to be plugged into a wall outlet, not even when you’re designing it!
3. Within reason, I should be able to touch your electromagnet with my bare hands when it is on. I understand that you will need to have some bare wires to connect to the power source and such, but for the most part it should be safely designed to allow handling.
4. Do not attempt any “exotic” wiring setups unless you know **<u>exactly</u>** what you are doing.

Each group needs to have a copy of the sheet on the following page. Marks for the actual electromagnet will be recorded the day that it is demonstrated. You will then be graded on the lab report you write up, which is to be handed in the next day. The total mark for the entire project is out of 36.

Names:

Electromagnet Mark Sheet

Strength of Electromagnet:

Excellent 10	Fantastic 9	Great 8	Good 7	Acceptable 6	Passable 5	Below Expectations <5
Picks up and maintains hold on iron rod.	Picked up iron rod for a moment, but could not maintain.	Picks up hole punch (or similar sized object).	Picks up scissors or large clips.	Picks up several paper clips.	Picks up one paper clip.	Unable to pick up any iron object.

Creativity and Use of Materials:

	Excellent 4	Proficient 3	Basic 2	Weak 1
Creativity	Amazing artistic creative concept that is a once in a lifetime innovative idea.	Obvious that more time invested in design than most would consider committing to.	Simple design, nothing fancy, but looks OK.	Extremely simple electromagnet that appears to have been thrown together.
Use of Materials	Multi core/layer. Controlled by a switch. Design facilitates ease of use.	Multi core/layer. Controlled by a switch.	Single core/layer. Controlled by a switch.	Single core/layer. Difficult to turn on by directly touching wires to battery.

Total Electromagnet Mark: / 18

Lab Report:

Lab report to be submitted ***the day after*** the in class demonstration of your electromagnet. Follow the modified format with only the following sections:

Objective
What you're trying to build.

Hypothesis
Main idea/concept behind what makes an electromagnet an electromagnet.

Equipment
Stuff you're using to make the electromagnet.

Procedure
Instructions to build the electromagnet.

Observations
Chart showing what you successfully picked up.

Sources of Error
Things that might have caused your electromagnet to not work as well as it could have.

Total Lab Report Mark: /18

Lab 18: Marshmallow Speed of Light

Number of Students	Two	Chapter	13: EMR	Marks	26

By examining the melting of marshmallows in a microwave oven, we can come up with a rough measurement of the speed of light.

Caution

Be very careful while “cooking” the marshmallows in the microwave. Do not leave them at any time. Be aware that the main ingredient is sugar, and they could start to burn very suddenly. Be ready to turn off the microwave at any moment. As long as you only run the experiment to the point where they start to melt (probably about 10 – 15s), you will be fine.

Objective:

To measure the speed of light.

Equipment:

- Microwave oven
- Bag of marshmallows
- Microwave safe plate
- Microwave safe coffee mug

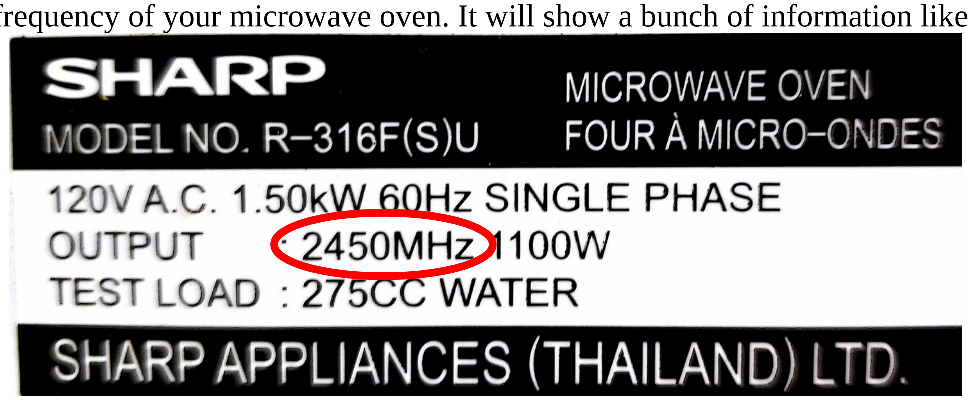
Procedure:

Completely cover the plate in a layer of closely placed marshmallows, making sure that it is only one marshmallow deep (don't stack them). It will be easiest if your make sure they are sitting on the plate on their flat end.

You will have to remove the spinning glass turntable (carefully!) from your microwave, and place the mug upside down over the spinning “knob” thing on the bottom. That way when you put the plate of marshmallows on top it will ***not*** spin.

With the marshmallows in the microwave, start cooking them until you see them start to melt in a few spots. Stop the microwave and quickly mark those spots. Measure the distance between ***adjacent*** “hot spots.”

If safe, and with help if necessary, turn the microwave around and look for a label on the back to find out the exact frequency of your microwave oven. It will show a bunch of information like this…



In the unlikely event that the label is missing or does not show a value, you may use the *approximate* value of 2.4 GHz.

Post-Lab Question:

What relationship did you observe for the distance between the melted spots and the wavelength for the microwave ovens you used in your experiment?

Lab 19: Mirrors and Lenses

Number of Students	Four	Chapter	13: EMR	Marks	21

Using a series of lenses, mirrors, and a light source we can examine several different effects. Each of the following exercises can be considered as a mini-lab, taking only about five minutes each.

Caution: Although the light source being used is only a regular bulb, you should still be careful to not look directly into the beam, especially when it is passing through a lens. Also, you will be using a small dish with water in it near your light source. Be careful of the electrical hazard this poses. Take care to not scratch or drop any of the optical equipment being used.

A: Index of Refraction of Water

Objective: To measure the index of refraction of water.

Equipment:

- Single beam light source
- Semicircular dish half filled with water
- Protractor

Procedure:

1. Place the dish on top of the paper and trace around it. Somewhere near the centre of the flat side of the dish mark a dot. This is where you will always aim your incident ray.
2. Shine the single beam at an angle so that it strikes the dish as at the dot. Trace this beam on the paper and mark it as "Beam 1_i"
3. Measure where the refracted beam exits the dish by looking for the brightest beam on the curved side of the dish. Mark this point as "Beam 1_r". Later, when you've finished and moved the dish out of the way, you can connect this dot to the dot on the flat side to trace the refracted ray.
4. Repeat steps 2 and 3 for several different incident angles, marking each with their own "Beam" numbers.
5. When you are done several trials, remove the dish. Draw a normal line perpendicular to the flat side at your original dot. Measure all the angles of your incident and refracted rays.

Analysis:

Use each of your trials to calculate the index of refraction for water, then average your values. Your measurement of the refractive index of water is _____ . The percent error compared to the accepted value of 1.33 is ____ %.

B: Offset of light as it passes through a solid

Objective: To observe the how much a beam of light is offset as it passes in and out of a high refraction solid.

Equipment:

Single beam light source
Solid transparent block
Blank paper sheet
Ruler

Procedure:

1. Place the block on top of the blank sheet. Trace a faint line around it in pencil.
2. Aim the beam at an angle to the surface of the block.
3. Trace the incident ray in the air to where it initially strikes the block. Also trace the ray on the other side where it exits the block.
4. Remove the block and extend you two rays. There should look like parallel lines.
5. Measure the displacement between the two beams, perpendicular to both.

Analysis:

The displacement between the incident and exiting beams is ____ cm.

Post-Lab Question:

1. How would you explain the displacement between the incident and exit beams.

C: Law of Reflection (Plane Mirror)

Objective: To confirm the law of reflection for plane mirrors.

Equipment:

Single beam light source
Plane Mirror
Blank paper sheet
Protractor

Procedure:

1. Place the plane mirror on the blank paper, and trace a faint line along its reflective surface.
2. Aim the beam at an angle to the surface.
3. Trace the incident ray of light to where it strikes the mirror, and trace the reflected beam.
4. Remove the mirror and draw a normal line where the ray struck.
5. Measure the incident and reflected angles.

D: Focal Length (Converging and/or Diverging Mirror)
Objective: To identify the focal length of a curved mirror.

Equipment:
Multiple beam light source
Curved Mirror(s)
Blank paper sheet
Ruler

Procedure:
1. Place the curved mirror on the blank paper, and trace a faint line along its reflective surface.
2. Aim the multiple light beam source at the mirror, trying to align the incident beams as much as possible with where the principle axis would be.
3. Trace the incident and reflected beams.
4. Measure the focal length.

Analysis:
The focal length of the mirror is ______ .

E: Focal Length (Converging and/or Diverging Lens)
Objective: To identify the focal length of a lens.

Equipment:
Multiple beam light source
Lens(es)
Blank paper sheet
Ruler

Procedure:
1. Place the lens on the blank paper, and trace a faint line along its surface.
2. Aim the multiple light beam source at the lens, trying to align the incident beams as much as possible with where the principle axis would be.
3. Trace the incident and refracted beams.
4. Measure the focal length.

Analysis:
The focal length of the lens is ______ .

Lab 20: Wavelength of a Laser Lab

Number of Students	Two	Chapter	13: EMR	Marks	26

Objective:
The purpose of this lab is to measure the wavelength of a commercially available laser using several different forms of gratings.

Hypothesis:
Make sure to note the wavelength listed on your laser.

Equipment:

Consider ***any*** exposure (direct or indirect) of the laser to your eye as ***dangerous***.
Most lasers used will be red. If the laser you are using is missing its label, assume the accepted wavelength is 700nm.
Gratings will always have information printed on them about lines/mm (or something like that). Make sure you take note of these values while performing your lab. CDs have a spacing of 1600nm between their groves, while DVDs have a spacing of 740nm. Avoid touching the surfaces of gratings, especially the glass diffraction grating. It is very easy for oil from your fingers to reduce their effectiveness.

Procedure:
For the two gratings you should make sure your laser passes through. When using the CD and DVD to laser must bounce off.

Observations:
Replica diffraction grating spacing = ___________ lines / mm (must be converted to d)
Glass diffraction grating spacing = ___________ lines / mm (must be converted to d)

Diffraction Grating Used	d (m)	*l* (m)	$\mid x_{right} \mid$ (m)	$\mid x_{left} \mid$ (m)	$\mid x_{ave} \mid$ (m)
Replica Grating					
Glass Grating					
CD					
DVD					

Analysis:
You will first need to determine which method (small angle approximation or sine theta method) is appropriate based on your observations. Then calculate the wavelngth. There is no linear regression in this lab analysis.

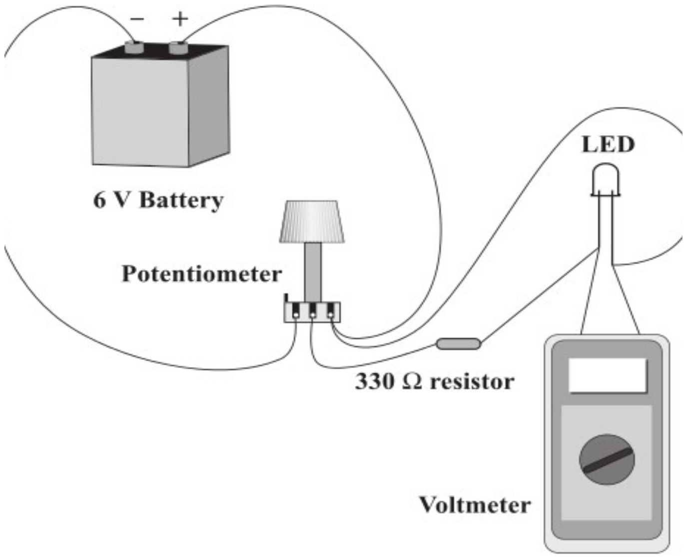
Error:
Determine which grating produced the most accurate result.

Post-Lab Question:
Before CDs people mostly listened to music recorded on LP records. Explain if you would be able to perform this lab with an LP instead of a CD.

Lab 21: Measuring Planck's Constant

Number of Students	Two to Four	Chapter	14: Quantum Mechanics	Marks	24

Background:
When large enough a voltage is applied to a light emitting diode (LED) it will cause current to flow. Each individual electron that crosses between the two semiconductors inside the LED loses energy that is converted directly into a single photon. By slowly increasing the voltage on a LED until it is first observed to give off light (individual photons), we can indirectly measure the value of Planck's constant.



Objective:
To determine the value of Planck's Constant.

Equipment:
5 different LEDs
6V Battery
1 kΩ potentiometer (variable resistor)
330 Ω resistor
voltmeter
5 connecting wires (with alligator clips)

Procedure:

Caution: Do not stare directly at a **bright** LED. It can be very harmful to your vision.

Building the Circuit
The circuit may already have been put together for you. If not, refer to the diagram as you follow the instructions. Improperly wiring the circuit could severely damage the components. ***Notice that your LEDs have one terminal that is slightly longer than the other.***

1. Set the potentiometer with the terminals facing you. Turn the knob fully clockwise (maximum resistance setting).
2. Connect the negative terminal of the battery to the left-hand terminal of the potentiometer, and the positive terminal of the battery to the right-hand terminal of the potentiometer.
3. Choose you first LED that you wish to test. Connect the **short** terminal of the LED to the 330 Ω resistor. Connect the **long** LED terminal to the right-hand terminal on the potentiometer. Connect the resistor to the centre terminal of the potentiometer.

Performing the Experiment

1. Connect the voltmeter across the LED, with one terminal from the voltmeter touching one of the connection points. Set the voltmeter to “20” (or next nearest setting).
2. Take a black piece of paper and roll it into a tube. Hold this around the LED to block outside light and look through the tube at the LED
3. Slowly increase the voltage across the LED by ***slowly*** turning the potentiometer counter-clockwise until the LED just barely begins to glow. It will help if one person turns the dial while another person focuses on looking at the light. Go back and forth across this voltage a few times to make sure that you measure the exact voltage as accurately as possible.
4. Reset the potentiometer to maximum resistance by turning the knob all the way clockwise. Disconnect the LED, put in the next LED, and repeat.
5. Continue until all 5 LEDs have been measured.

Observations:

Record your data in a table using the following given values...

Color of LED	Red	Amber	Yellow	Green	Blue
Frequency ($x10^{14}$ Hz)	4.54	5.00	5.08	5.31	6.38
Voltage (V)					

Analysis:

Plot a graph of voltage as a function of frequency. Use this graph as a suitable averaging technique to determine your experimental value for Planck's Constant.

Lab 22: Millikan's Oil Drop Experiment Gedanken

Number of Students	Solo	Chapter	15: Atomic Models	Marks	26

The class has decided to try to reproduce Millikan's Oil Drop Experiment. The equipment was set up with the plates oriented to float negatively charged oil droplets. A variable voltage supply was connected to the plates so that you could adjust the voltage across the plates during different trials. The plates themselves are fixed at a distance of 1.85 cm apart. The class has used a computer program to take the data you collected (hundreds of individual trials) and break them up into data groups that correspond to a particular number of excess electrons on the oil drop. This just means that everyone in a particular group has data that corresponds to the same number of excess electrons on all their oil drops, say seven electrons for example. Only trials that resulted in a floating oil drop were recorded. All other trials were ignored.

Illustration 1: Millikan's actual oil drop experiment equipment.

Objective:
Determine the number of excess electrons on the oil drop.

Pre-Lab Question:
In Millikan's time, he did not have a computer to separate data into groups that all had the same charge. Explain how this was a disadvantage to him, and what sort of a pattern he needed to look for in his data.

Observations:
There are four sets of quantitative data for this lab. You will be assigned to use the data from ONE of these groups.

Group Alpha

Trial	Voltage (V)	Mass of Oil Drop (kg)
1	2.00e6	3.70e-12
2	2.25e6	4.56e-12
3	2.50e6	3.75e-12
4	2.75e6	5.58e-12
5	3.00e6	5.03e-12
6	3.25e6	4.87e-12
7	3.50e6	6.17e-12
8	3.75e6	6.94e-12
9	4.00e6	6.70e-12
10	4.25e6	6.74e-12
11	4.50e6	9.12e-12
12	4.75e6	8.79e-12
13	5.00e6	9.70e-12
14	5.25e6	1.06e-11
15	5.50e6	9.70e-12

Group Beta

Trial	Voltage (V)	Mass of Oil Drop (kg)
1	2.00e6	7.41e-12
2	2.25e6	7.93e-12
3	2.50e6	9.48e-12
4	2.75e6	9.94e-12
5	3.00e6	1.03e-11
6	3.25e6	1.06e-11
7	3.50e6	1.30e-11
8	3.75e6	1.32e-11
9	4.00e6	1.52e-11
10	4.25e6	1.46e-11
11	4.50e6	1.47e-11
12	4.75e6	1.72e-11
13	5.00e6	1.85e-11
14	5.25e6	1.99e-11
15	5.50e6	1.94e-11

Group Gamma

Trial	Voltage (V)	Mass of Oil Drop (kg)
1	2.00e6	5.82e-12
2	2.25e6	5.55e-12
3	2.50e6	5.95e-12
4	2.75e6	7.76e-12
5	3.00e6	7.93e-12
6	3.25e6	7.74e-12
7	3.50e6	8.95e-12
8	3.75e6	1.16e-11
9	4.00e6	1.16e-11
10	4.25e6	1.01e-11
11	4.50e6	1.19e-11
12	4.75e6	1.30e-11
13	5.00e6	1.41e-11
14	5.25e6	1.53e-11
15	5.50e6	1.45e-11

Group Epsilon

Trial	Voltage (V)	Mass of Oil Drop (kg)
1	2.00e6	9.35e-12
2	2.25e6	1.01e-11
3	2.50e6	1.06e-11
4	2.75e6	1.24e-11
5	3.00e6	1.24e-11
6	3.25e6	1.46e-11
7	3.50e6	1.48e-11
8	3.75e6	1.55e-11
9	4.00e6	1.80e-11
10	4.25e6	1.80e-11
11	4.50e6	1.94e-11
12	4.75e6	1.97e-11
13	5.00e6	2.20e-11
14	5.25e6	2.36e-11
15	5.50e6	2.38e-11

You goal is to report back to the class how many excess electrons were on your oil drops according to the data you have. In order to do this you will need to write up an entire lab report, with the following considerations in mind:

1. The lab depends on the fact that F_e must equal F_g to be able to float the oil drop. Keep in mind that there are various formulas associated with this. Refer to the notes on Millikan's Oil Drop Experiment.
2. Based on the formulas and your data, come up with set of values that, when graphed, will have a slope equal to the charge "q."
3. Sketch your graph. *Note: Your origin does not have to be zero-zero for the graph.* You will need to calculate the slope of the graph.
4. Your value for "q" should be *close* to a whole number multiple of the elementary charge "e." You'll have to figure out what whole number multiple of "e" is closest to your value of q. Calculate your percent error compared to this ***multiple*** of e.

In your conclusion make sure to state how many **excess** electrons you think were on your oil drops.

Lab 23: Half Life Gedanken Lab

Number of Students	Solo	Chapter	16: Nuclear Physics	Marks	25

A horrible accident has happened! A container holding a radioactive isotope broke open and contaminated a classroom in the school. Because of a problem with the labeling, it could any one of the following isotopes:

Berkelium-242 (420 s half life)
Plutonium-235 (1518 s half life)
Americium-246 (2340 s half life)
Curium-249 (3849 s half life)

Objective:

Identify the isotope.

Pre-Lab Questions:

1. One of the reasons to identify the isotope is to be able to say what type of decay it is going through. Which type of decay would present the greatest danger, and would just closing off the room be good enough to ensure the safety of staff and students?
2. How likely is it that you would be able to visually see a change in the material over the next few hours?

Equipment and Procedure:

There is some concern about exactly which isotope was spilled. For the time being the room has been closed off, but you are allowed access to take some readings. A basic Geiger-Muller Tube (aka Geiger Counter) has been supplied to you. It will give you a reading of the radiation being emitted measured in Bequerels. You have placed the detector in the room and remotely collect some data over a few hours in order to identify the isotope. You are not required to write up a procedure for this lab.

Observations:

There are four sets of quantitative data for this lab on the next two pages. You will be assigned to use the data from ONE of these groups. Each of these groups contains a large amount of data, taken over several hours. Group Epsilon does not have data after 6500 s because the amount of radiation dropped below what the Geiger-Muller tube could detect (essentially zero).

Analysis:

Graph the data. Use a suitable averaging technique to **determine** the half life and **identify** the isotope.

Group Alpha

Trial	Time Elapsed (s)	Radiation (Bq)
1	0.00000	250.00
2	500.00	198.97
3	1000.00	158.36
4	1500.00	126.03
5	2000.00	100.31
6	2500.00	79.83
7	3000.00	63.54
8	3500.00	50.57
9	4000.00	40.25
10	4500.00	32.03
11	5000.00	25.49
12	5500.00	20.29
13	6000.00	16.15
14	6500.00	12.85
15	7000.00	10.23
16	7500.00	8.14
17	8000.00	6.48
18	8500.00	5.16
19	9000.00	4.10
20	9500.00	3.27
21	10000.00	2.60
22	10500.00	2.07
23	11000.00	1.65
24	11500.00	1.31
25	12000.00	1.04
26	12500.00	0.83
27	13000.00	0.66
28	13500.00	0.53
29	14000.00	0.42
30	14500.00	0.33
31	15000.00	0.27
32	15500.00	0.21
33	16000.00	0.17

Group Beta

Trial	Time Elapsed (s)	Radiation (Bq)
1	0.00000	250.00
2	500.00	228.47
3	1000.00	208.80
4	1500.00	190.82
5	2000.00	174.39
6	2500.00	159.37
7	3000.00	145.65
8	3500.00	133.11
9	4000.00	121.65
10	4500.00	111.17
11	5000.00	101.60
12	5500.00	92.85
13	6000.00	84.86
14	6500.00	77.55
15	7000.00	70.87
16	7500.00	64.77
17	8000.00	59.19
18	8500.00	54.09
19	9000.00	49.44
20	9500.00	45.18
21	10000.00	41.29
22	10500.00	37.73
23	11000.00	34.49
24	11500.00	31.52
25	12000.00	28.80
26	12500.00	26.32
27	13000.00	24.06
28	13500.00	21.98
29	14000.00	20.09
30	14500.00	18.36
31	15000.00	16.78
32	15500.00	15.34
33	16000.00	14.01

Group Gamma

Trial	Time Elapsed (s)	Radiation (Bq)
1	0.00000	250.00
2	500.00	215.58
3	1000.00	185.91
4	1500.00	160.31
5	2000.00	138.24
6	2500.00	119.21
7	3000.00	102.80
8	3500.00	88.65
9	4000.00	76.45
10	4500.00	65.92
11	5000.00	56.85
12	5500.00	49.02
13	6000.00	42.27
14	6500.00	36.45
15	7000.00	31.44
16	7500.00	27.11
17	8000.00	23.38
18	8500.00	20.16
19	9000.00	17.38
20	9500.00	14.99
21	10000.00	12.93
22	10500.00	11.15
23	11000.00	9.91
24	11500.00	8.29
25	12000.00	7.15
26	12500.00	6.16
27	13000.00	5.32
28	13500.00	4.58
29	14000.00	3.95
30	14500.00	3.41
31	15000.00	2.94
32	15500.00	2.53
33	16000.00	2.19

Group Epsilon

Trial	Time Elapsed (s)	Radiation (Bq)
1	0.00000	250.00
2	500.00	109.54
3	1000.00	48.00
4	1500.00	21.03
5	2000.00	9.21
6	2500.00	4.04
7	3000.00	1.77
8	3500.00	0.75
9	4000.00	0.34
10	4500.00	0.15
11	5000.00	0.07
12	5500.00	0.03
13	6000.00	0.01
14	6500.00	0.01
15	7000.00	-
16	7500.00	-
17	8000.00	-
18	8500.00	-
19	9000.00	-
20	9500.00	-
21	10000.00	-
22	10500.00	-
23	11000.00	-
24	11500.00	-
25	12000.00	-
26	12500.00	-
27	13000.00	-
28	13500.00	-
29	14000.00	-
30	14500.00	-
31	15000.00	-
32	15500.00	-
33	16000.00	-

Appendix A: Laboratory Report Format

The following guidelines apply to any lab report that you submit. Remember, all labs you produce should look professional, just as an actual researcher would produce for a scientific journal. You will be marked accordingly.

- **Reports should be typed**, but if written then it must be written in ink on one side of lined white paper .
- Calculations for the *Analysis* section can be done in the document, as a spreadsheet (computer or calculator), or written in pencil on paper and handed in separately.
- Graphs must be done in pencil on graph paper, on a spreadsheet, or in a Nspire tns file.
- The lab must be written using full sentences. The exception to this is the equipment list, which is done in an itemized format like a shopping list.
- Any papers handed in must be stapled in the top left hand corner and include all group member's names, the block, and date in the top right corner. Please don't hand in duo-tangs or things like that.
- **The preferred method of submitting your lab report is to use Google Classroom.** Any files you submit (documents, spreadsheets, tns files, etc.) ***must*** all use the following naming system. For these examples we will assume a student named John Smith is sending me his work for Lab 7: Elevator Lab. Even though he worked with a group of students, one of whom is from a different class, John Smith is the one taking responsibility to submit the work so no other names appear in the file name. All of these files would be submitted through **Google Classroom**.

  John Smith typed up his lab document → smith7
  He did his analysis as a spreadsheet → smith7
  John also did some analysis work on his Nspire handheld → smith7.tns
  He also took a picture of some work he did on a sheet of paper → smith7.jpg

Notice that the file names do *not* contain any other names.

If you write out a portion of the lab on paper (this applies to Analysis and Error Calculations ***only***), you may submit those to your teacher the next school day.

In the event that you are unable to use Google Classroom, paper copies can be handed in. Speak to your teacher in advance.

On the following page is an outline of the format that your lab ***must*** follow. Failure to follow this outline will result in lost marks.

Each Group Member's Full Name
Block Number
Date

Title of Lab

I. Objective:

State what you are trying to do or discover. This is usually a simple, single sentence that does *NOT* talk about how you are going to try to figure it out.

II. Hypothesis:

Three parts to this section. **First**, make an educated guess as to what you think the outcome will be (probably an accepted value). Make sure you actually give an answer to what our objective is asking... don't start discussing other stuff. **Second**, you must show the physics formula (identifying its variables with units) that is the basis of your lab. Do not include "math" formulas. **Third**, list the manipulated, responding, and controlled variables for your lab. Hint: you should probably be looking at the formula you just write down for ideas of which is which.

III. Equipment:

Make a list (in point form like a shopping list) of the equipment you will be using. You do not list things like your pencil and calculator. We only need to identify the equipment that was necessary for you to perform the experiment itself. Sometimes you might want to include a labeled diagram of the setup you used.

IV. Procedure:

Make a numbered outline of the steps you did to actually perform the lab itself. Be brief but complete. As a rule of thumb, I should be able to show your lab to a grade seven student and they would be able to complete the lab based on your instructions, even though they might not understand what the lab is about or how to analyze it. Don't bother telling me to "gather materials" or to "clean up at the end." **Do *not* explain how to analyze the data here.**

V. Pre-Lab Questions:

Sometimes questions might be assigned as part of the lab that you are supposed to answer ***before*** starting the lab. Answer those questions here.

VI. Observations:

Most of the time you measured a bunch of numbers during the lab. These are your ***quantitative*** measurements, and they must be organized in a table. If you noticed noteworthy things, like a smell or color, you may also describe these ***qualitative*** measurements here. ***Calculations or calculated numbers do NOT belong here!***

VII. Analysis:

This is where you do your "number crunching." Show any calculations that you need to do with your observations to come to a "final answer." If you need to create a linear graph (maybe to analyze something like its slope), you must show three things...

- the relationship between the slope and your physics formula
- an actual graph ***OR*** your unrounded slope and y-intercept values from your calculator
- your final calculated value with sig digs and units

See Appendix D for an example of what you MUST show.

VIII. Error:

List things that might have caused mistakes to happen while performing your lab... be specific! If your value is higher than the expected value, discuss errors that could have caused it to be higher. Keep in mind that listing things like “wrong formula” or “calculation errors” are not acceptable, since they are mistakes in your own work, not errors in performing the lab. You will also calculate percent error or percent difference (if applicable) in this section to figure out how far off you are.

IX. Concluding Statement:

Tie everything up here. Discuss your objective... did you answer it? Compare your hypothesis to your results... do they agree? You should clearly state your original hypothetical guess, your experimental result, and the magnitude of the error between them. Comment on your observations and analysis. Would you do something different next time? Can you suggest a different lab that is somehow related to this one? Use full sentences, and expect to write a pretty big paragraph or two.

X. Post-Lab Questions:

If any other question were assigned to you to answer after the lab, answer them here.

Appendix B: Marking Rubric

The following marking rubric will be applied to each section of your lab report. A typical lab report without any pre or post lab questions will be out of 24 marks. Failure to follow the format guidelines given will result in the following penalties:

Misnamed file (like “lab report.doc) = -1 mark
Disallowed file format (like docx file) = -1 mark
Missing information from top right of lab (e.g. name, block, date) = -1 mark
Failure to follow order of write up = -1 mark
Critical spelling or grammatical errors = -1 to -3 marks

	Excellent (3)	**Good (2)**	**Poor (1)**	**Unacceptable (0)**
Objective	Clear and concise statement of goal.	Workable statement of goal, some fuzziness.	Purpose of lab not clearly identified or understood.	“What was this lab about?”
Hypothesis	Reasonable educated guess, formula shown, variables identified.	Good guess and formula.	Guess or formula is missing.	“I think Elvis is the King!”
Equipment	Point form list of required equipment. Diagram if necessary/	Vital items listed, maybe one omission.	So many omissions that performing the lab would be difficult.	“We used that green gizmo with the lights.”
Procedure	Step-by-step numbered list the show how to do the lab.	Possible to do the lab, although some assumptions might have to be made. Might not be numbered,	Difficult to follow how lab was performed. Steps go off topic or are otherwise distracting.	“Just do it ®”
Pre-Lab Questions	Varies depending on questions assigned, if any.			
Observations	Collected quantitative data is well presented in a table. Qualitative data may be given if necessary.	All data is present, but shown in a format that may be confusing or misleading.	Some data is missing. Data shown in disorganized or sloppy manner.	“Were we supposed to write that number down?”
Analysis	Well laid out and calculated analysis based on data. Graphs (if needed) follow all rules and have appropriate calculations showing relationship between calculated value and physics concept.	Calculations are essentially correct, although some parts may be implied, including values calculated from the graph.	Work is poorly shown, as if a rough draft. Serious calculation errors affect results.	“The answer is 5.4e6 m/s. Uh, or maybe 2 m/s. Can I get back to on this?”
Error	Several sources of error are listed, and each is well explained. Shows calculation of error (if appropriate).	List of sources of error is incomplete. Calculation of error is wrong.	Seriously lacking list of sources and/or no calculation of error.	“My sock got caught on the dial-thingy... is that a problem?”
Conclusion	Wraps up the lab, just like the conclusion of an essay for English.	Shows the person has not lost sight of the lab's reason, but could focus more on what's going on.	Has serious trouble showing link from Objective through to Conclusion.	“The End.”
Post-Lab Questions	Varies depending on questions assigned, if any.			

Appendix C: Error Calculation Formulas

In high school labs, don't be surprised if you obtain errors as high as 25% or higher. The important part is, can you ***explain*** your errors! Consider a lab a success if you are under about 10% error, and an amazing success if you are under 5%.

Percent Error

Percentage Error is the most common way of measuring an error. This is the correct method to use when you have an accepted value to compare your measured value from your experiment to.

$$Percent\ Error = \frac{(measured - accepted)}{accepted}$$

Example: You complete a lab to measure the acceleration due to gravity. During the lab you measured a value of 9.04 m/s^2, and the accepted value from your data sheet is 9.81 m/s^2. **Determine** the percent error.

$$Percent\ Error = \frac{(measured - accepted)}{accepted}$$

$$Percent\ Error = \frac{(9.04 - 9.81)}{9.81}$$

$$Percent\ Error = -0.078491 = -7.85\%$$

Warning!
The minus sign on the answer is perfectly fine! It just means that your measurement is ***under*** the accepted value. You have just as much chance to be under as over the accepted value.

Percent Difference

Percent Difference is useful if you have two measurements you've taken and you wish to see how different they are as a percentage. This is handy when you do **not** have an accepted value for comparison.

$$Percent\ Difference = \frac{difference}{average}$$

Example: You have measured the motion of a toy car using two different methods. The first method gave you a measurement of 8.4 m/s and the second method came out as 7.1 m/s. Determine the percent difference.

$$Percent\ Difference = \frac{difference}{average}$$

$$Percent\ Difference = \frac{(8.4 - 7.1)}{\left(\frac{8.4 + 7.1}{2}\right)}$$

$$Percent\ Difference = \frac{1.3}{7.75} = 0.167742 = 17\%$$

Warning!
Although it really doesn't matter which number you put first to calculate the difference, it is traditionally set up so that you will get a positive value on top.

Appendix D: Linear Regressions used as a "Suitable Averaging Technique" in the Analysis Section

In many of the labs you are asked to use a "**suitable averaging technique**" or "**appropriate line straightening technique**" to analyze your data. This does ***not*** mean that you are supposed to use a formula for each of your trials, and then add them and divide by the number of trials. Although this is a mathematical "average" it is not what we need to do.

Instead, you will need to create a graph of your data and then find the line of best fit, also known as a **linear regression**. The reason this works so well is that the linear regression will take into account all of your data while making sure that all of them contribute to the best overall "average" value. This is ***never*** about plugging numbers straight into a physics formula to get an answer.

The process of figuring out what to graph and what it means follows the same essential steps for all the line straightening questions you might be faced with. It seems complicated when shown as a bunch of steps, but makes more sense when you actually apply it to doing a problem. Often, but not always, you will also need to identify any variables that are exponential. This just means that they are being squared, cubed, square rooted... something like that. If nothing in your formula is exponential then you don't need to worry about it.

The following example will show you how to work through the necessary steps. You need a basic understanding on kinetic energy (like in Science 10) to get through this. **In a lab write up these are the steps you need to show in the Analysis section of your lab report.** Even if you do a bunch of the graph work in a spreadsheet or on your graphing calculator, you still must show all this reasoning out work.

A student is observing the motion of a cart on a track using a motion sensor. The computer collecting the information displays it as a chart with the following data:

Trial	v (m/s)	E_k (J)	
1	5.0	2.4	
2	10	11	
3	15	23	
4	20	38	
5	25	63	

Using a suitable averaging technique, **determine** the mass of the cart. As part of your response, **complete** the data table so that the values (when plotted) produce a linear relationship, **provide** a graph of the kinetic energy as a function of the values you determined, **determine** the slope of your graph, and **relate** the slope algebraically to a physics equation.

This is more like an exam question then what you will see in the labs in this book, but it is a great example in that the question is basically telling you what to do to analyze your lab data. Remember, since you are being told to do a graphical analysis you can ***NOT*** simply plug your energy and velocity values into a formula and solve for mass. The formula for kinetic energy is important, but only as a way to discover a relationship in the data we graph.

1: Identify the formula, and identify the exponential variable(s) if any.

It's gotta be the formula for kinetic energy, since the question is about a moving mass that has kinetic energy. In the data we have, we know about the velocity and kinetic energy, so from the formula...

$$E_k = \frac{1}{2} m v^2$$

$$E_k \alpha v^2$$

...we get that the kinetic energy is directly proportional to the ***velocity squared***.

2: Come up with new data table.

Since we've identified that velocity is squared, we better do exactly that. We're not putting numbers into a formula, we're just taking the velocity from each trial and squaring it.

Trial	v (m/s)	E_k (J)	**v^2 (m^2/s^2)**
1	5	2.4	**25**
2	10	11	**100**
3	15	23	**225**
4	20	38	**400**
5	25	63	**625**

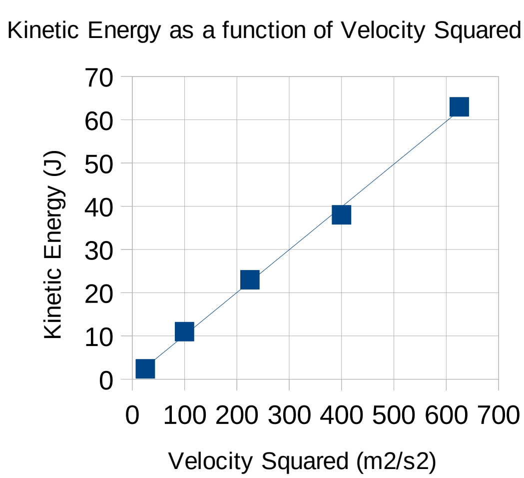
The best way to do this is on a spreadsheet or graphing calculator, since you can get it to do the calculations for you. Ask your teacher with help in using a spreadsheet or graphing calculator if you are not sure how to use them, or watch the Line Straightening and Linear Regression videos on the Multimedia page at studyphysics.ca .

3: Graph the data

For this example we will show kinetic energy as a function of velocity squared. We don't need the velocity anymore, since we've already adjusted it by squaring to get our linear relationship.

If you use a computer spreadsheet, remember to choose "XY Scatter" as the graph type, not "Line."

You can either draw this by hand on graph paper, or use a spreadsheet, or graphing calculator. If you do it on a graphing calculator, it is NOT necessary to show an actual drawn out graph. See the next step for further information.



4: Calculate the slope

You can do this two ways, depending on how you made your graph.

The first method is used if you made your graph **on graph paper**. You MUST choose two points along the line of best fit. Do not use the data points!!! The two points I will use are (200, 20) and (500, 50).

$$slope = \frac{y_2 - y_1}{x_2 - x_1}$$

$$slope = \frac{50 - 20}{500 - 200}$$

$$slope = 0.10 \frac{J}{m^2 / s^2}$$

We can safely have 2 sig digs in our slope answer, since we have 2 sig digs in all the original values given to us. I'll use an unrounded number on my calculator for later steps.

The second method is used if you made your graph **on a spreadsheet or graphing calculator**. Again, you should check with your teacher about exactly how to do this on your device. You should get the more precise values of...

m = 0.098930481282422
b = 0.27411764705883

The “m” used here is the math symbol for “slope” and is NOT the physics variable “mass.” It's just a coincidence they both use the letter m.

Which you will record with no sig digs. Yes, this is a lot more sig digs than we have, but if you did the linear regression on your calculator, you must show **both** these values with **all** the digits to prove that you did it that way. You can round off for sig digs in your final answer at the end. I'm going to use this more precise slope value for our calculation in step 7 below.

5: Evaluate the slope

Use the slope formula and the actual variables that you graphed to figure out what the slope represents...

$$slope = \frac{\Delta y}{\Delta x} = \frac{E_k}{v^2}$$

$$slope = \frac{E_k}{v^2}$$

We graphed E_k on the y axis and v^2 on the x axis. That's how I know which one is on the top and which is on the bottom.

6. Manipulate your fundamental formula to look like the slope manipulation

Manipulate the kinetic energy formula to solve for the same arrangement that the slope is equal to...

$$E_k = \frac{1}{2} m v^2$$

$$\frac{E_k}{v^2} = \frac{1}{2} m$$

$$slope = \frac{E_k}{v^2} = \frac{1}{2} m$$

$$slope = \frac{1}{2} m$$

$$2(slope) = m$$

Notice in the second step, the formula has been manipulated so the stuff on the left is the same as what we figured out the slope is equal to in step 5.

7. Solve for your unknown

$$2(slope) = m$$

$$m = 2(slope)$$

$$m = 2(0.098930481282422)$$

$$m = 0.197860962567 = 0.20\,kg$$

So at the end of the analysis in your lab report (and in your conclusion!) you will state that the mass of the object was 0.20 kg.

Appendix E: FAQ

Question
So it's ok if I call my file "**momentum super lab from steve joe and philip.doc.docx**"?
Answer
No. The file must be named using ONLY the last name of the person sending the file. Also, notice that the person sending it thought typing "doc" on the end would make it ok, but Word still saved it with "docx" on the very end. *Ask if you need help saving in the correct format.*

Question
I don't know how to set up a spreadsheet to graph.
Answer
There are several videos explaining this on the Multimedia page of www.studyphysics.ca.

Question
I don't know how to set a linear regression in a spreadsheet or on a TI 83, 84, or Nspire handheld.
Answer
There are several videos explaining this on the Multimedia page of www.studyphysics.ca.

Question
If I copy and paste my graph into the lab document, do you still want the spreadsheet?
Answer
Yes. If anything is squirrelly about your calculations, it might be necessary to look at the spreadsheet.

Question
If I email the lab before midnight on the due date, when do I hand in the analysis stuff I wrote on paper or did on an Nspire?
Answer
Next school day.

Question
I did my analysis and/or error calculations on paper. Can I skip that section in the lab write-up?
Answer
Nope. You still need to have those sections and tell me where to look for your written out work. In those sections just say something like "see attached sheet." It is better to scan and insert those parts in your lab document if possible.

Question
Where do I get that free program for making documents and stuff?
Answer
LibreOffice.org