Physics 101 Lab Manual

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Contents

How to Write Labs

0.1 What You Need to Bring to the Lab

You will need to bring the following to the labs:

- Pencils and an eraser,
- A 30 cm (12 inch) ruler,
- A calculator,
- Loose-leaf paper on which to write the lab.

0.2 The Pre-Lab

Each lab has a set of pre-laboratory exercises which must be completed *before* you arrive at the lab. Pre-lab questions will be graded along with the labs.

0.3 Structure of the Labs

The first page of your lab should include

- the title
- your name and student number
- your lab partner's name

During the labs, you will be required to answer questions, draw sketches, make graphs and tables of data and write a short summary.

Questions are to be answered on loose-leaf paper, unless stated otherwise. They must be written in proper english. Please avoid point-form answers.

Some labs require simple **calculations** to be done. Remember to show how the calculation is done. If a calculation is repeated many times (for example, when filling out a table), the details only need to be shown once.

For each lab, a short **summary** must be written. The summary should describe (a) the main purpose of the lab and (b) your most important findings. The purpose of the summary is to help you see the "big picture", so you

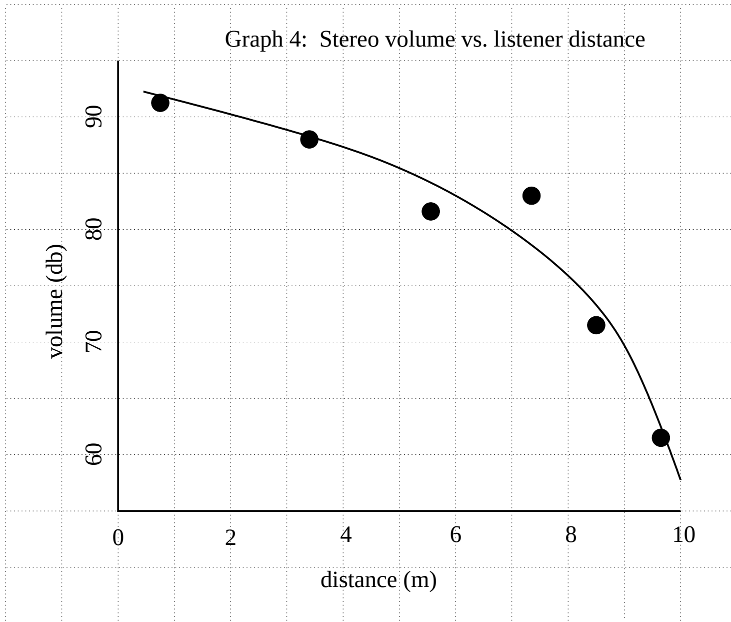

Figure 1: Sample graph showing how to draw a smooth curve.

shouldn't simply repeat all of your results. When you write the summary, make sure you look at the objectives for the lab, and say something about each of them. The summary should answer two questions: "What physical principle or phenomenon did we study?" and "What did we actually learn about it?" The summary must be written in proper english.

0.4 How to Draw Graphs

A sample graph is shown in Fig. 1. When you draw a graph, pay attention to the following rules:

- All graphs need to have a *title* and a *number*. For example "Graph 1: Radiation penetration in lead".
- When drawing a graph of "A" versus "B", put "A" on the vertical axis and "B" on the horizontal.
- Graphs should be drawn in pencil.
- Graphs must be drawn on graph paper.
- Make the graphs big. Use as much of the page as possible *BUT* keep it simple. The entire page could have been used in Fig. 1 if each square

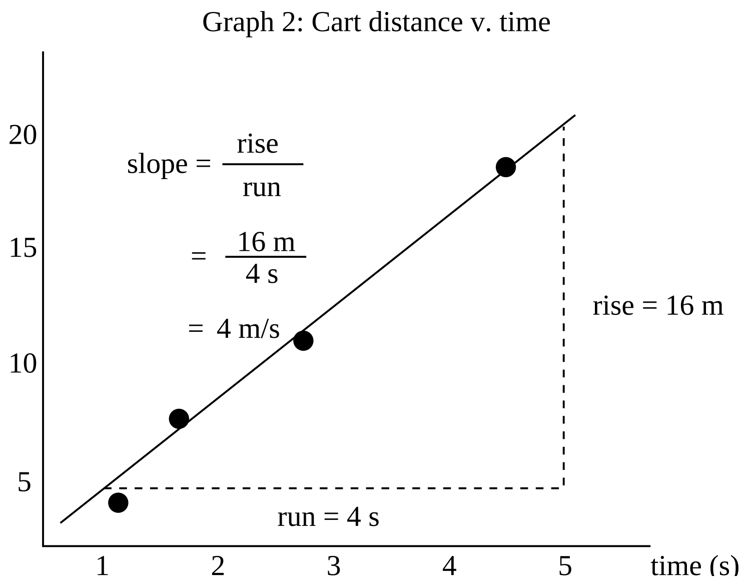

Figure 2: Sample graph showing how to calculate the slope.

were 0.77 m instead of 1 m, but this just makes graphing complicated, and doesn't add anything to the final product.

- Make sure you label the axes of your graph. If the x-axis indicates time measured in seconds, then it should read "time (s)".
- Make sure you draw the scale on the graph.

When you are asked to draw a **smooth curve** through your data, the curve generally will not pass through all the data points. This is justified because of there is always a small amount of uncertainty (known as **error**) in making a measurement.

If the graph is a straight line, then often we want to find the **slope** of the graph. The slope of a straight line is found by drawing a triangle like the one shown in Fig. 2, and determining the **rise** (the length of the triangle in the y-direction) and the **run** (the length of the triangle in the x-direction). The slope is then given by

$$\text{slope} = \frac{\text{rise}}{\text{run}}$$

Notice that if the curve goes down, then the rise is negative and the slope is negative. Notice also that the **units** of the slope are given by the units of the y-axis over the units of the x-axis. If the y-axis is cm, and the x-axis is seconds, then the slope of a line on the graph is in cm/s. Finally, remember to **show your calculations** on the graph, as done in Fig. 1.

Chapter 1

Pre-Lab Questions

1.1 Observations of Venus and Mars

Reading: Hobson Ch. 1

You may answer these questions directly on the figures.

This section looks at the simplest orbital system: the earth and the sun. The aim of this section is to give you some practice connecting what we see on earth to the earth's orbital motion. Figure 1.1 shows two views of the earth. Figure 1.1 (a) shows a "side-view", with North pointing upwards. Figure 1.1 (b) shows a "top-view", with North pointing out of the page towards you.

Question #1: In Fig. 1.1 (b) there are three arrows shown at point A on the earth's equator. The arrows are labelled 1, 2, and 3. For a person standing at point A, which arrow points East, which points West and which points straight up into space?

- Figure 1.2 is a schematic figure (not to scale) of the earth in orbit about the sun. As in Fig. 1.1 (b), the view is from the "top", so that North points directly out of the page towards you. The earth is shown at a particular instant in time.

Question #2: The points A and B indicate two different points on the earth's surface. At each point, draw arrows indicating West and East, assuming that North points out of the page towards you. Next, using the fact that the sun rises in the East, draw the direction of the earth's daily rotation.

- The time at a particular point on the earth's surface is determined by it's location relative to the sun. If the sun is directly overhead, then it is noon. On the opposite side of the earth, where "up" points directly away from the sun, it is midnight. At points half-way in between midnight and noon, it is either 6 pm or 6 am.

Question #3: Estimate the time to the nearest hour at points A and B.

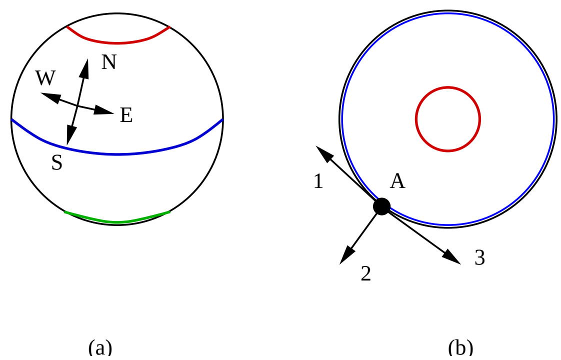

Figure 1.1: Two perspectives of the earth. In (a), the four compass directions are also shown at a particular point on the earth's surface in the Northern hemisphere. In (b), the North pole points directly out of the page towards you [ie. you are looking down from the "top" of (a)].

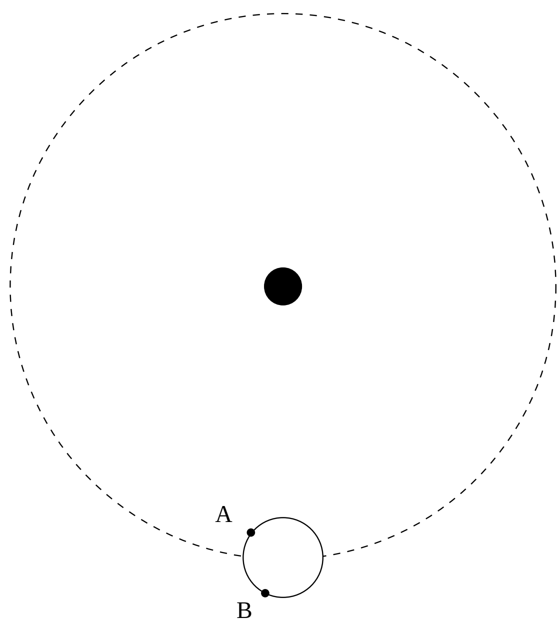

Figure 1.2: The earth in orbit around the sun.

1.2 Diffusion

Reading: Hobson Ch. 2.4 and section 3.3 of this lab

Question #1: Define diffusion. *Hint:* There is a glossary in the back of Hobson.

- Figure 1.3 shows a cartoon of a random walker. Initially, the walker starts at 0. A coin is tossed and the walker moves one position to the right if the coin lands "heads" and one position to the left if the coin lands "tails". We represent the position of the walker by a number r.
- Perform your own random walker experiment. Start at $r = 0$ and toss a coin 20 times. For each "tails" subtract 1 from r, and for each "heads" add 1 to r. Record this in a table. Note that r can be positive or negative.
- Read the section "How to draw graphs" in the introduction to the lab manual. Draw a graph of r vs. N (the number of coin tosses), following the guidelines set out in the introduction.

Question #2: Describe, in words, the relationship between r and N for your random-walker experiment. In other words, is there a pattern in the way r changes when you increase N? Is there anything predictable about the motion of your random walker?

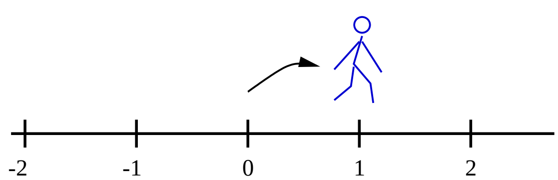

Figure 1.3: The random walker. If the coin-toss is "heads" the walker moves one step to the right; if the coin-toss is "tails" the walker moves one step to the left. In this figure, the walker is moving from $r = 0$ to $r = 1$.

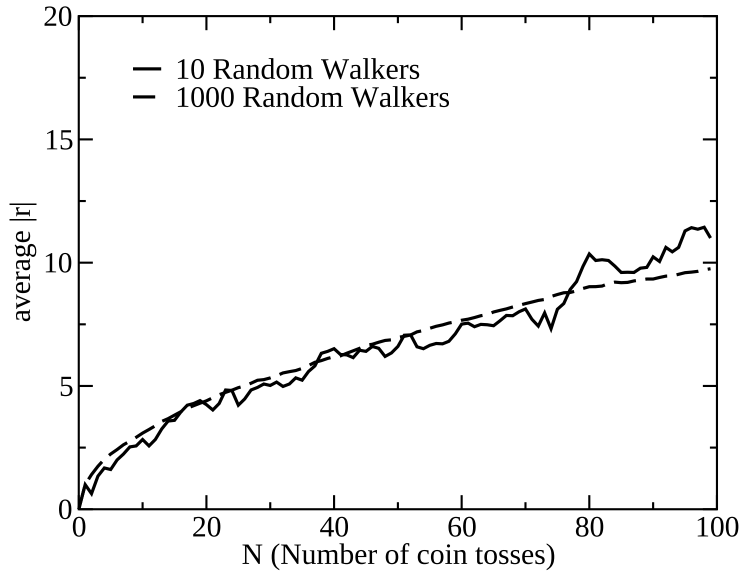

Figure 1.4: Average distance travelled for many random walkers. This data is generated by having a computer toss a coin 100 times for each random walker, and then averaging the results. Try writing a simple program to do this yourself!

- Figure 1.4 shows the average of $|r|$ for 10 random walkers and for 1000 random walkers. The symbol $|r|$ refers to the *absolute value* of r, which means dropping the minus sign (if there is one) in front of the number. Thus $|-5| = 5$, $|-3.7| = 3.7$, and $|10| = 10$. The figure shows the average distance of 1000 random walkers from their starting place after 1, 2, etc. coin tosses. This data was generated by a computer which tossed a coin 100 times for each random walker. The data was then averaged over all the random walkers. The data shows that, for 1000 walkers, the random walkers have moved an average of 1.87 steps away from their origin after 5 coin tosses. This means that some walkers have moved 1 step away, some have come back where they started from, and a few have even moved a full 5 steps away.

Question #3: Compare the average motion of the random walkers with your coin tossing experiment. What do you notice about the *average* motion of the random walkers as the number of walkers is increased? Note that each *individual* random walker still moves completely randomly!

Question #4: From your graph, can you estimate what $|r|$ will be for your single random walker after 30 coin tosses? How much confidence do you have in your estimate?

Question #5: From Fig. 1.4 estimate the average value of $|r|$ for 1000 random-walkers after 150 coin tosses. How much confidence do you have in your estimate?

Question #6: Which has more predictability, the motion of an *individual* random walker or the *collective* (average) motion of a large number of random walkers?

- A theory or an equation has predictive power if it can predict the outcome of an experiment which has not yet been performed.

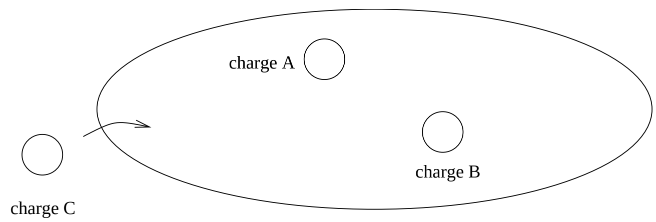

Figure 1.5: Two charges (A and B) are placed in an object. A third charge (C) is added later.

1.3 Electrostatics and Electricity

Reading: Hobson Ch. 8.4, 8.6, & 8.7

Use the principles given in the Objectives part of the lab (section 4.1) to answer the following questions:

Question #1: Look at Fig. 1.5. Two charges (labelled A and B) are placed in some object (for example, a piece of glass or a piece of metal). Assume for the moment that both charges are electrons. If the material is a conductor, how will the electrostatic forces make them move? Where will they stop?

Question #2: How will the charges move in the conductor if charge A is an electron and charge B is a positive ion? Where will they stop?

Question #3: After the charges in the previous problem stop moving, a third charge (charge C) is put into the conductor. Do you expect it to feel a force? Give your reasoning.

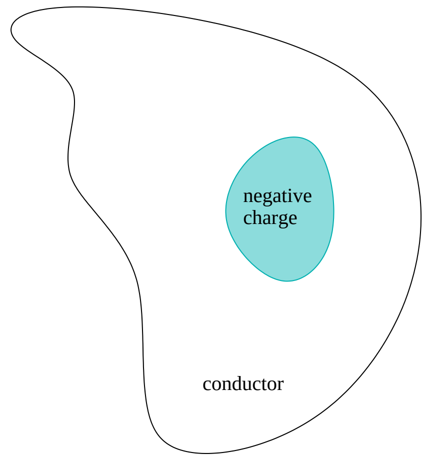

Figure 1.6: Some extra negative charge is placed in a conductor. How does it move?

Question #4: How will the charges in Fig. 1.5 move due to the electrostatic forces if the material in which they are placed is an insulator?

Question #5: Figure 1.6 shows a conductor that has some extra electrons placed on it. Describe how the excess negative charge moves? How is it distibuted when it stops moving?

1.4 Electrical Resistance, Power, and Energy

Reading: Section 5.2 of this manual, Hobson Ch. 6.7, 8.6, 8.7

Question #1: How much energy does each Coulomb of electrons carry as it leaves a 1.5 V "D"-cell battery?

Question #2: If there is a voltage drop of 1.5 V across a resistor, how much energy does each *Coulomb* of electrons lose as it travels through the resistor?

Question #3: If there is a voltage drop of 1.5 V across a resistor, how much energy does each *individual* electron lose as it travels through the resistor? Remember: always show your calculations.

Question #4: What is the power lost by electrons flowing through a resistor if the current is 2.2 amps and the voltage drop across the resistor is 1.5V?

Question #5: How much energy does a 100 W lightbulb use in 1 hour?

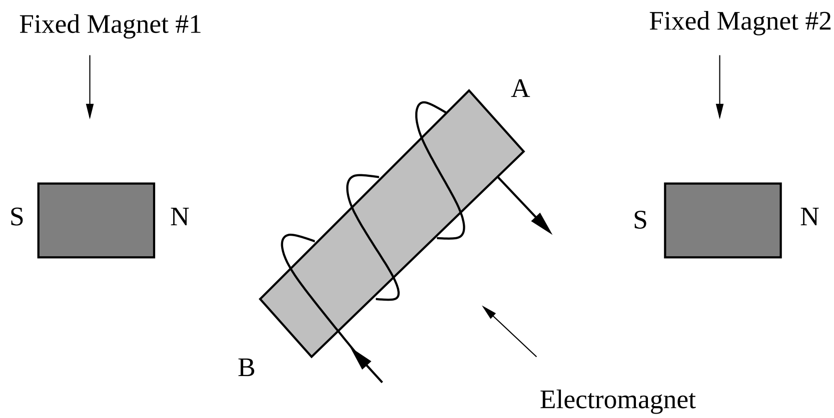

Figure 1.7: An electromagnet and two permanent magnets.

1.5 Electromagnetism

Reading: Hobson Ch. 8.5

In order to answer the pre-lab questions, you need to know the "left-hand rule for coils":

> **Left-hand rule for coils:** Wrap the fingers of your **left hand** around the coil in the same direction that electron current flows around the coil, and your thumb will point towards the north end of the magnet.

Question #1: Look at Fig. 1.7. The figure shows an electromagnet (a coil of wire wrapped around an iron bar) and two fixed permanent magnets. Assume a current flows in the direction of the arrows. Indicate (on the figure) the North and South poles of the electromagnet using the left-hand rule for coils.

Question #2: Draw an arrow showing the direction of the force on the end "B" of the electromagnet exerted by fixed magnet #1.

Question #3: Draw an arrow showing the direction of the force on the end "B" of the electromagnet exerted by fixed magnet #2.

Question #4: Repeat the last two questions for the end "A" of the electromagnet.

Question #5: If the electromagnet were free to move, how would it move? Assume the permanent magnets are fixed in place.

Question #6: How could you make the electromagnet move in the other direction?

1.6 Atomic Spectra

Reading: Hobson Ch. 9.2, 9.4, 14.1

The following hypothesis is a *classical theory* which tries to explain why a light bulb emits light. It is classical because it ignores the wave-like properties of atoms.

Hypothesis 1 *Incandescent light comes from a tungsten filament encased in a glass bulb.*

1. *Electric current passes through the tungsten filament and heats it up.*
2. *Tungsten atoms vibrate randomly when heated. They move more when they are hotter.*

Question #1: Use the fact that atoms are made of charged protons and electrons to explain why the random vibration produces light. *Hint:* Recall the discussion in Hobson Ch. 9.2.

Question #2: Consider an experiment where you produce waves on a string by moving one end up and down with your hand. What is the relationship between the frequency of your hand (ie. the number of times per second you move your hand up and down) and the frequency of the wave on the string?

Question #3: What do you think is the relationship between the frequency of atomic vibration in the tungsten filament and the frequency of emitted light? Based on this hypothesis, what frequencies should be present in the light emitted by the filament?

Question #4: If the atoms are hotter, then we can expect that they will move *faster* and *farther*. What do you think that this would do to the brightness of the light? What about the colour of the light?

Question #5: What is the energy transformation which occurs when light is produced? In other words, where does the energy for the light come from? Give answers in terms of both *macroscopic* and *microscopic* energies.

1.7 Radioactivity

Reading: Lab Manual section 8.2, Hobson Ch. 15.1-15.3

Question #1: What are the four fundamental forces?

Question #2: Which fundamental force holds the nucleus together?

Question #3: Which fundamental force is responsible for α-decay?

Question #4: Which fundamental force is responsible for β-decay?

Question #5: Write down the reaction equation for the β-decay of ^{90}Sr (Strontium-90).

Question #6: Write down the reaction equation for the α-decay of ^{239}Pu (Plutonium-239).

Chapter 2

Observations of Venus and Mars

2.1 Objectives

1. To learn what information can be deduced about the planets based on changes in their appearance when they are observed over a period of several months.

2. To understand differences in the appearances of superior and inferior planets.

2.2 The Earth's Orbit

The following questions are based on Fig. 2.2. The questions may be answered directly on the figure.

Question #1: If Fig. 2.2 shows the position of the earth on February 13, draw, as accurately as possible, the position of the earth on April 13, two months later. Recall that the earth orbits the sun in the same direction that it rotates on its axis. The angular distance travelled by the earth can be computed. Recall that the earth travels 360 degrees in one year, so that in 19 days it travels

$$\frac{19}{365} \times 360 = 18.7 \approx 19 \text{ degrees.}$$

From this we can see the earth travels approximately one degree per day. You may use this approximation throughout this lab.

Question #2: Draw the new position of point A on April 13, if it is the same time of day as shown for February 13.

Question #3: A star is directly overhead at midnight on February 13. Draw an arrow showing the direction to the star. At what time of day will the star be directly overhead on April 13? You can figure this out from the sketch you drew in Question 4.

- Note that stars are very far away, so that the arrows pointing to the star on February 13 and April 13 will be nearly parallel. For the scale shown in Fig. 2.2 (representing the earth's orbit by a circle a few inches across), the nearest stars would be approximately 1 mile away.

2.3 Phases of the Moon

The "phase" of the moon refers to how it is illuminated by the sun. The "full moon" is the phase in which the entire side of the moon facing the earth is illuminated. A "crescent moon" has only a small sliver illuminated. In this section, you will examine the relationship between the phases of the moon, and the orbital motion of the moon.

Figure 2.3 shows the moon in orbit around the earth. The moon is shown at three different points in its 28-day orbit. The following questions may be answered on the figure.

Question #4: Assuming that North points out of the page, draw the direction of rotation of the earth, and the direction the moon travels along its orbit. The moon orbits in the same direction the earth spins.

Question #5: At each of the three locations shown, shade the night side of the moon with a pencil. Note that light comes as parallel rays from the sun, as shown in the figure.

Question #6: For each case, make a sketch of the of the moon showing how you would see it from Earth.

Question #7: Indicate which of the three phases of the moon is closest to "full" and which is "crescent".

2.4 The Phases and Orbital Motion of Venus

In this section, you will make the connection between a sequence of telescope observations of venus and venus's orbital motion. Venus is an *inferior* planet, which means that the radius of its orbit is smaller than that of the earth. This section is a little more complicated than the previous sections because the motions of both venus *and* the earth need to be considered.

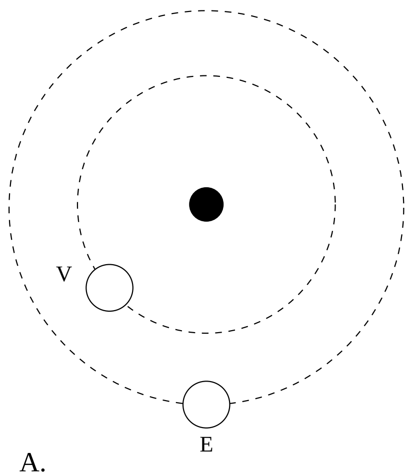

Figure 2.1: The earth-sun-venus system.

You will be given a data sheet showing a series of telescope-photos of venus taken over a 5 month period. Answer the following questions regarding the data.

Question #8: Using the fact that North is up in the photos, how can you tell that the observation on Jan. 19 was made in the evening (and not just before dawn)?

Question #9: Why does venus change size in the photos?

Question #10: Figure 2.1 shows two possible arrangements of the earth-sun-venus system. Which of these corresponds most closely to the January 19 observation? Give your reasons.

Question #11: Figure 2.4 shows the earth-sun-venus system with the earth's position shown on the date of the first venus photo (Jan. 19/01). Use the data shown in the handout to find the location of venus on the observation dates listed below. This must be done in several steps.

a.) First you need to determine where the earth is on the observation dates. Make a table like the one shown below

Date	Days Elapsed since Jan. 19
Jan. 19	0
Feb. 20	32
Mar. 21	
Apr. 13	
May 8	

The left-hand column shows the dates on which the observations were made. The right-hand column shows how much time has elapsed since the Jan. 19 observation. For example, Feb. 20 is

$$20 + (31 - 19) = 32 \text{ days}$$

later than Jan. 19. Recall that the earth travels one degree in one day. Complete the table for the remaining observation dates.

b.) Draw, directly on fig. 2.4 and as accurately as possible, the positions of the earth on each of the observation dates.

c.) Next, draw as accurately as possible the positions of venus on the observation dates. To do this, you will need to use information contained in the handouts; the telescope observations tell you how the size and illumination (by the sun) of venus changes. From this, you can determine the relative positions of the earth and venus.

d.) Based on your results, estimate the length of the venusian year.

2.5 Mars

You have also been given a series of photos of mars taken from the Hubble Space Telescope over a period of nearly 1 year. Mars is a *superior* planet, which means that the radius of its orbit is larger than that of the earth.

Question #12: Compare the martian and venusian photos. Why do we sometimes see a “crescent venus” (only a thin sliver is illuminated) but never a “crescent mars”? Note that the radius of mars’s orbit is *bigger* than the radius of earth’s orbit.

Question #13: Why can you often see mars at midnight, but never venus?

2.6 Summary & Conclusions

Write a short summary of the lab which addresses the issues raised in the Objectives. For example, you might consider the following questions:

- How do the appearances of venus and mars change as they move?
- Why do they change appearance?
- In what ways are they similar? Different?
- What is the reason for their similarities/differences?

Question #14: [**Bonus Question**] Are the data sheets (the photos of venus and mars) compatible or incompatible with a geocentric (earth-centered) model of the solar system? Is there any feature of the data which can be used to rule a geocentric model out?

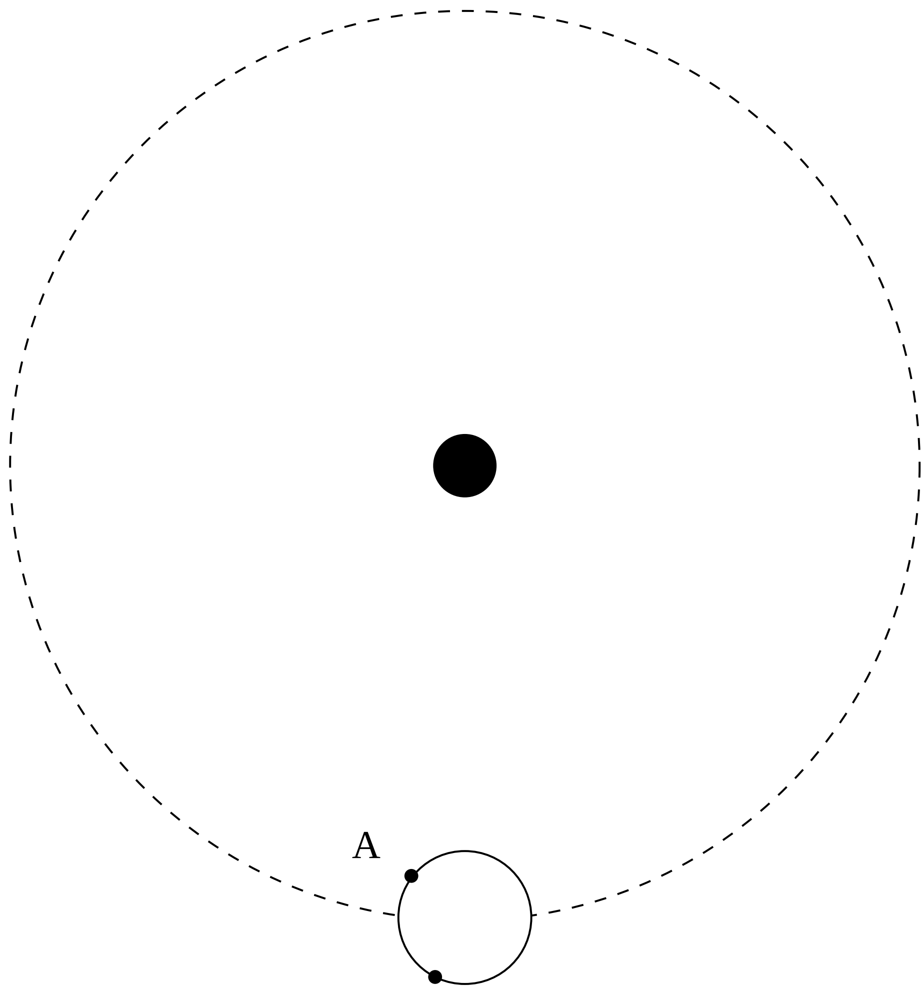

Figure 2.2: The earth in orbit around the sun.

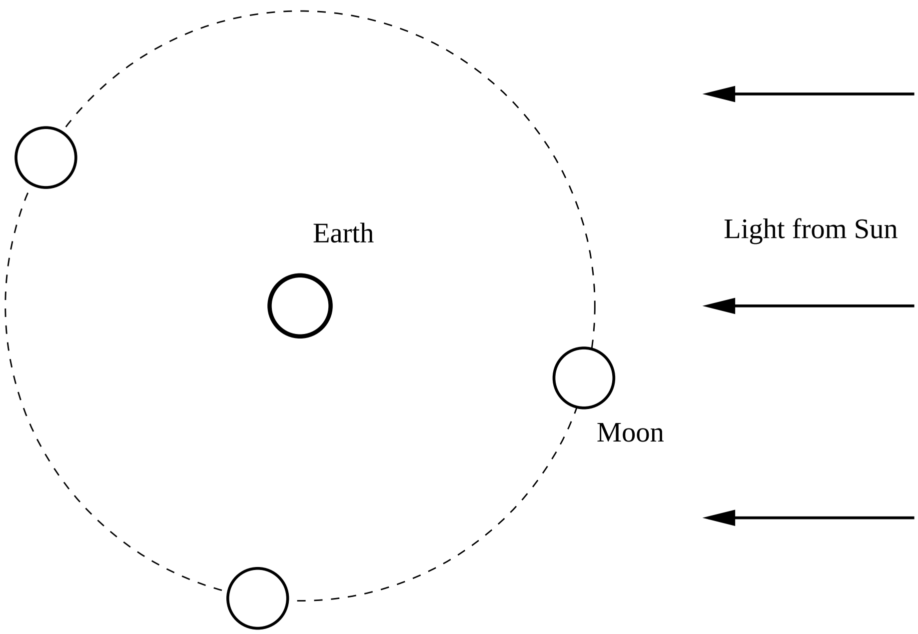

Figure 2.3: The moon in orbit around the earth.

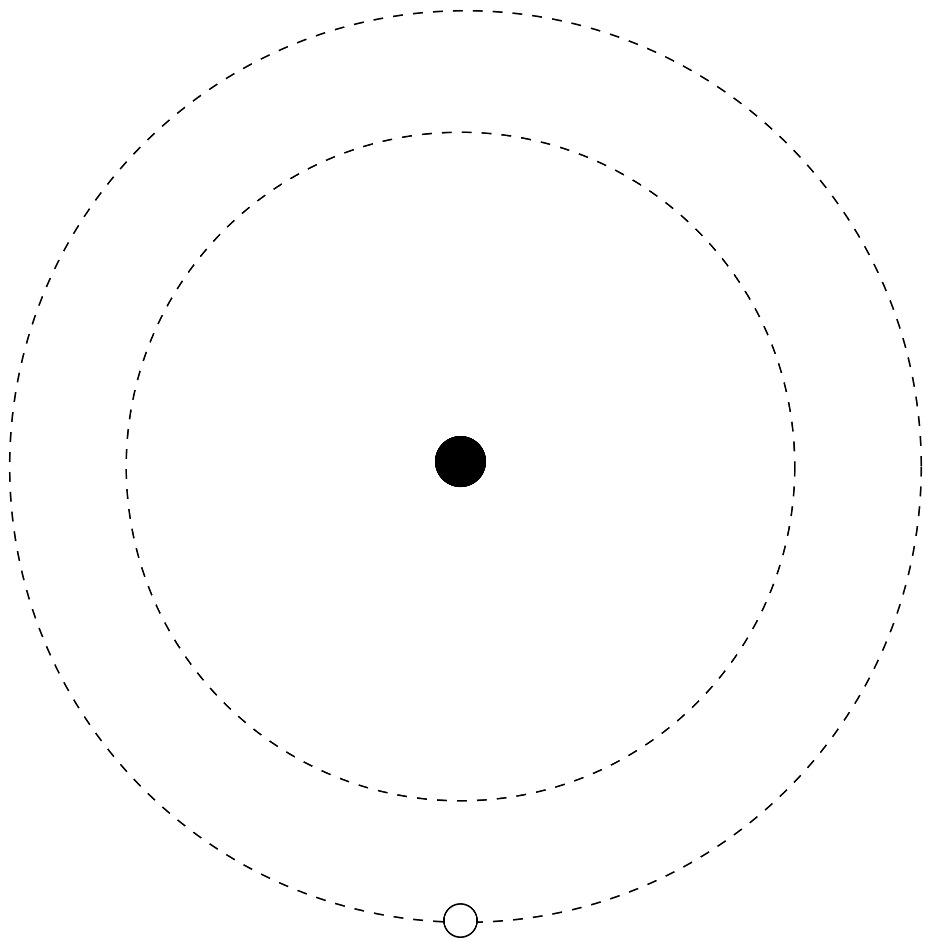

Figure 2.4: The earth-sun-venus system.

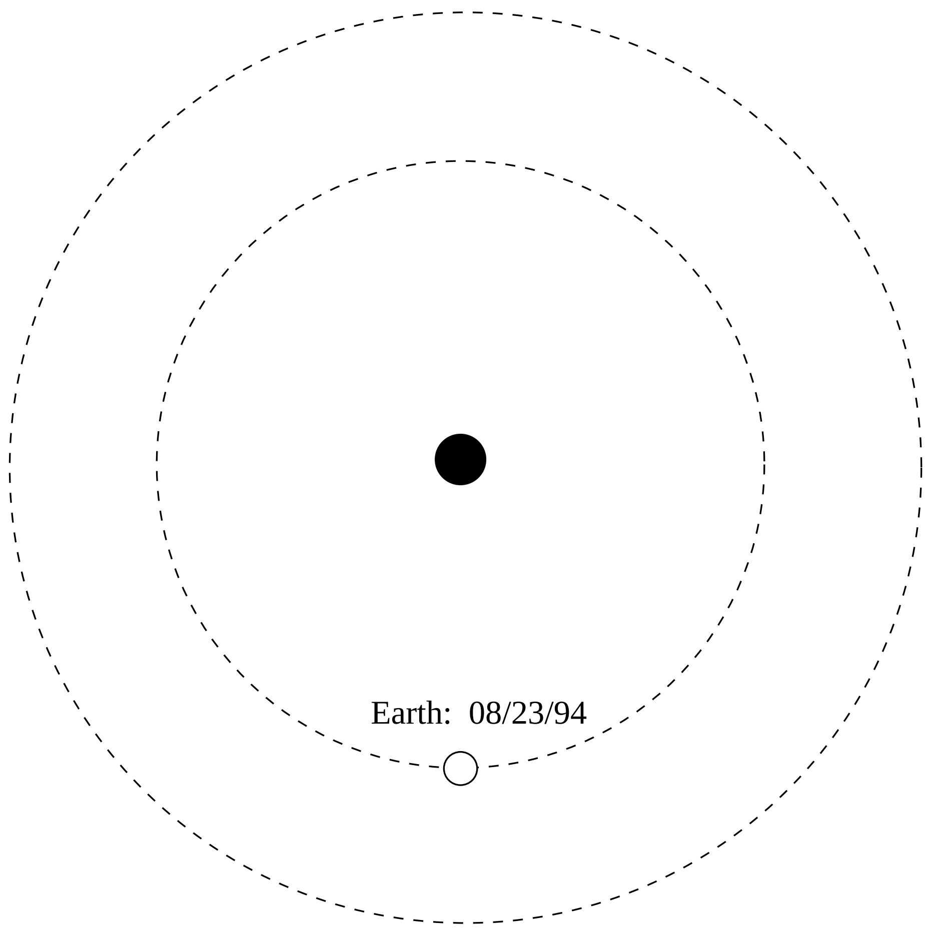

Figure 2.5: The earth-sun-mars system.

Chapter 3

Diffusion

3.1 Objectives

This lab studies several important concepts:

1. The concept of predictive power.
2. The microscopic model of diffusion.
3. The difference between the microscopic and macroscopic motion of ink molecules in water.

3.2 Diffusion of Ink in Water

- Fill the bottom of the petrie dish with a thin layer of water. Read the instructions below thoroughly before beginning your experiment.
- Set the petrie dish on top of the ruler so that the centimeter scale of the ruler is clearly visible and passes through the center of the dish, as shown in Figure 3.1.
- Make a table like the one below:

Time (s)	Position of left edge (cm)	Position of right edge (cm)	d (cm)

- In the first three columns you will record the position of the left and right edges of the ink drop at different times as it expands. In the fourth column you will record the diameter d of the ink-drop.

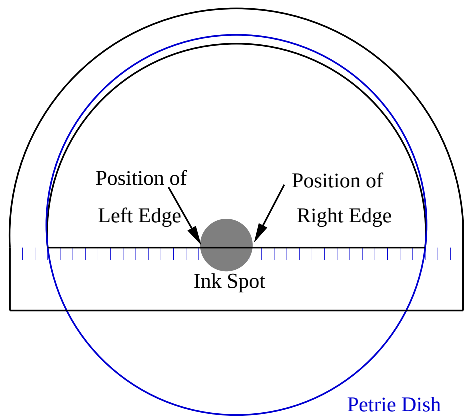

Figure 3.1: Experimental Setup for Diffusion Lab.

- Carefully place a *small* ink drop near the middle of the petrie dish, over the edge of the ruler (as shown in Figure 3.1) and start timing. You need to centre the ink drop on the edge of the ruler so that you measure its diameter.
  - If you don't get a nice compact ink drop, you should start again. It may take several tries.
  - This experiment works best if the water is at room temperature. If the water is too cold, you will get convection currents.
- Make measurements of the positions of the left and right edges of the ink-drop at 15 second intervals for the first two minutes. After two minutes, make observations every 30 seconds. Continue until at least 180 seconds (3 minutes) have passed.
- Make a graph of the ink-drop diameter d vs. the elapsed time. Instructions on how to draw graphs are given in the introduction. Draw a smooth curve through the data points.

Question #1: Describe in words the relationship between d and t. Is it predictable?

Question #2: The ink-spot expands more slowly at large times. Does this mean that the individual molecules are slowing down?

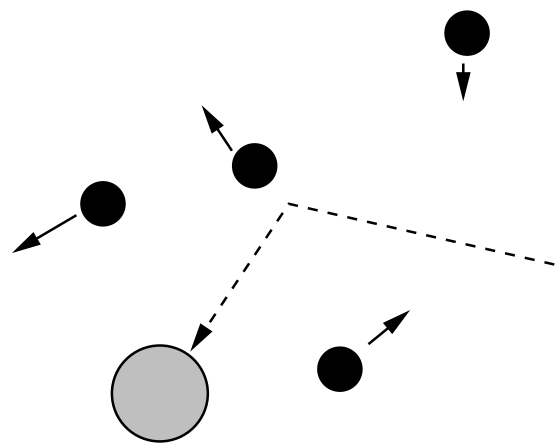

Figure 3.2: The path of an ink molecule (the large gray molecule) through water (the small black molecule).

3.3 Microscopic Model

Consider a simple model for diffusion, illustrated in Fig. 3.2. This is the *microscopic diffusion model.*

1. The Petrie dish contains two types of molecules—ink molecules and water molecules. The molecules move in random directions.

2. Ink molecules move in a straight line until they bump into another molecule.

3. During a collision, a molecule is scattered in a random direction. (In fact, the direction *isn't* really random. If we knew the details of exactly how each collision occured then the direction of the molecules after each collision could be predicted exactly.)

4. The molecule continues moving in a straight line until it bumps into another molecule.

5. Because of this random scattering the ink molecules move in a random walk. This means that the motion of an individual molecule is unpredictable.

6. Even though the motion of each individual molecule is random, the collective motion (ie. the average motion of many ink molecules) is predictable. This collective motion is called diffusion.

7. The *rate* at which molecules diffuse is measured by the "Diffusion constant" D. A large value of D means that molecules spread out quickly.

8. The diffusion constant D is determined by the kind of molecules diffusing, by the medium through which they diffuse, and by the temperature.

Question #3: The speed of a molecule is determined by its temperature (hot molecules move faster). How will temperature affect the diffusion constant D? Why?

Question #4: Since molecules are father apart in gases, they travel farther between collisions. Will D be larger or smaller in gases than in liquids? Why?

- If diffusing molecules can be thought of as random-walkers, then it should be possible to make a connection between the microscopic diffusion model and the coin tossing experiment.

- The following questions try to show that the coin-tossing experiment is a useful "toy-model" for diffusion. That means it is a simplified model which contains the basic ingredients to explain diffusion.

Question #5: Assume that the coin-tossing experiment can explain diffusion. What element of the microscopic diffusion model does a random-walker represent?

Question #6: What microscopic property of the ink molecules does the variable r from the coin tossing experiment represent?

Question #7: What element of the microscopic diffusion model does the variable N from the coin tossing experiment represent?

Question #8: What does each coin toss represent?

Question #9: What *macroscopic* property of the ink spot does the *average* r^2 represent?

3.4 Summary & Conclusions

What have we done here? This lab has many pieces to it so it can be a bit confusing. We studied a "random walker" model of diffusing molecules. In order to check whether this model works, we made a prediction that we could test. In this case, the prediction had to do with how the size of the ink spot changes with time.

Question #10: Compare your graph of d vs. t with the data for the average $|r|$ vs. N shown in Fig. 1.4. Are these two graphs consistent with each other? In other words, does your graph of d^2 vs. t support or contradict the random walker model of diffusion?

Question #11: Does this experiment prove that molecules exist? Does it support the theory that molecules exist? Justify your answer.

- Now write a brief discussion of the lab based on the objectives. You can turn each objective into a question by starting it with "What is..."

Question #12: Bonus Activity: If you perform the ink spot experiment with cold water (the colder the better), then after a minute or two of observing, you should see *convection cells* form. Describe them. Draw pictures if it will help.

Chapter 4

Electrostatics and Electricity

4.1 Objectives

To study some consequences of three fundamental principles of electricity:

1. Like charges repel, and unlike charges attract.
2. Electrons, which are negatively charged, move freely in a conductor, but cannot move through an insulator. Positive charges cannot move in solids, even if they are conductors.
3. A *neutral* material has as much positive charge as negative charge.

You should be able to explain all the observations you make in this lab with these ideas.

4.2 Electrostatics

- Figure 4.1 shows the electroscope. The essential feature is that two gold-foil leaves hang from a metal rod connected to a conducting ball. To begin with, make sure the leaves hang freely.
- Rub a piece of acetate (the clear plastic strip) with a dry and clean piece of paper and bring the acetate close to the silver conducting ball on the top of the electroscope. Then, touch the conducting ball on top of the electroscope with the acetate. Next, touch the ball with you hand. Next, repeat the process with the aluminum bar.
- Note: Sometimes the gold foil leaves will stick to themselves or to the glass plates on the front of the electroscope. This is undesirable, and you should try to avoid it when you do the experiments.

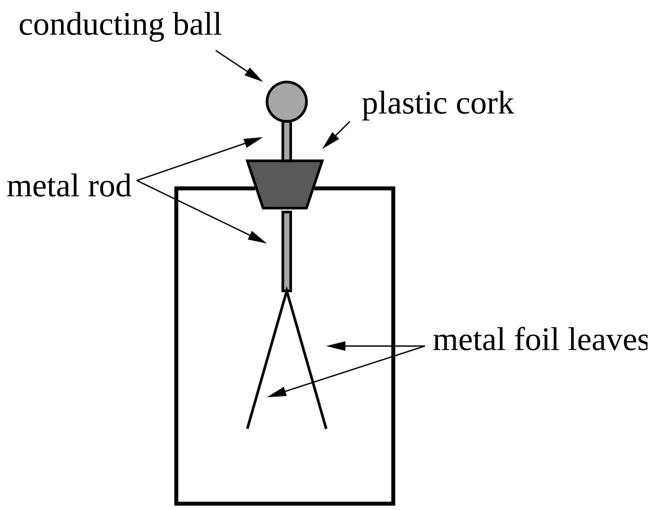

Figure 4.1: The electroscope

Question #1: Describe carefully what you observe as you perform the above experiments.

Question #2: The acetate is *positively charged* after being rubbed with the paper. Use this fact to explain your observations. Specifically, explain

1. how electrons move in the electroscope as you bring the acetate *close* (but not touching) to the electroscope. Make a sketch of the electroscope and acetate strip showing regions of positive and negative charge.

2. how electrons move when you touch the acetate to the conducting ball. Again, make a sketch of the electroscope and acetate strip showing how

charge flows, and what the final charge distribution looks like after the acetate strip has been taken away.

3. why the gold-foil leaves move in each case.

4. what happens to the charge on the electroscope when you touch it with your hand.

Question #3: The gold foil is connected to the ball by a metal rod, and this experiment shows that charge can be transferred through the rod to the gold foil. Why does the experiment not work when you touch the electroscope case with the acetate instead? (Try it).

- Ground the electroscope by touching the silver ball with your hand. The gold foil should return to its neutral "resting" position.
- Now, rub the vinyl strip (the white plastic strip) with the wool pad and touch the strip to the silver ball on the electroscope.
- Then, rub the acetate strip with the wool pad and bring it close to the ball on the electroscope.
- Finally, touch the acetate to the silver ball.

Question #4: Describe carefully what you observe in the above steps.

Question #5: What do your observations tell you about the charge on the vinyl strip? Give clear reasons. Make sketches showing (a) how charge moves when you bring the vinyl strip close to the electroscope and (b) how charge moves when you touch the electroscope with the vinyl strip.

- Ground the electroscope by touching the silver ball with your hand.
- Charge the electroscope with either the acetate or vinyl strip.
- Several pith-balls, which can be suspended by a nylon thread, are provided. Ground a pith ball by touching it with your hand. Then hold the pith-ball by the nylon thread, so it swings freely and bring it *slowly* closer to the electroscope.

Question #6: Describe carefully what you observe happening before, during, and after contact occurs between the pith-ball and the electroscope. Things happen quickly, and can be hard to see, so you may want to repeat this experiment several times. Also, note whether the gold-foil moves.

Question #7: Explain your observations in terms of the motion of electrons. Note that the pith-ball is a conductor, and that your answer to question 3 is important here. Divide your explanation into three categories:

1. Before the pith-ball makes contact with the electroscope.

2. During contact.

3. After the pith-ball makes contact with the electroscope.

4.3 The Concept of "Ground"

The concept of "ground" is extremely important in electricity. It refers to the fact that, given the chance, excess electrical charge will almost always flow into the earth. The next few questions elaborate on this point.

Think of the earth as a giant conducting sphere (yes, dirt conducts electricity, though not particularly well). Use the principles outlined in the Objectives to answer the following questions:

Question #8: Why does touching the electroscope with your hand discharge it completely, but touching it with a pith-ball only discharge it a little bit?

Question #9: Given the choice, why would excess charge on the electroscope prefer to flow into the earth, rather than into (for example) your body?

Question #10: All modern electrical appliances are "grounded". This means that the metal exterior of your toaster is connected to the earth by a wire. Why?

(Hint: This is a safety feature. Think about what would happen if a wire was broken and touched the side of the toaster.)

4.4 Conductors and Insulators:

- Most materials fall into one of two categories: either they are electrical *conductors* or electrical *insulators*. In fact, almost nothing is a perfect conductor or insulator, and most materials fall in between.
- We can describe how good a conductor a material is using the concept of *electrical resistance*. If the resistance is low, the material is a good conductor. If the resistance is high, the material is a poor conductor. A perfect conductor has no resistance and a perfect insulator has infinite resistance.
- Make a table like the one below:

Material	Resistance
aluminum rod	
plastic rod	
glass rod	
wooden block	
human hand	
rubber	
copper wire	
air	

- Charge the electroscope with either the vinyl or acetate strip. Then discharge the electroscope by touching the conducting ball with the aluminum bar. Notice (roughly) how long it takes for the electroscope to discharge, and use this to determine the resistance of the bar.
- In the second column, indicate whether the electrical resistance is low, medium, or high.
- Repeat the process for each material provided, as well as any others you want to include.

Question #11: When electricity was first introduced into homes, many people were nervous about the fact that electrical sockets didn't have plugs. They were worried that if nothing was plugged into the sockets, electricity would leak out of the holes into the room. Why doesn't electricity leak out of electrical sockets?

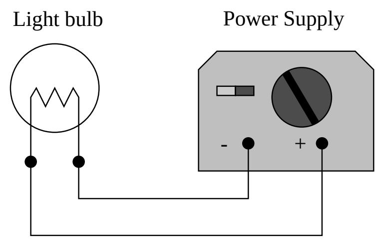

Figure 4.2: A simple electrical circuit.

4.5 Simple Circuits:

So far, you have established that electrons can flow through conductors, and that they will do so (a) to move away from areas of excess negative charge (b) to move towards areas of excess positive charge. This flow is called an electrical current. Electrical currents are useful to us because we can make the electrons do *work* while they move.

You can think of a power supply as a device which builds up excess positive and negative charges on its two terminals. If some conducting path is available, electrons will flow between the terminals because of the forces between the charges. In the next experiments, the electrons will do work illuminating a lightbulb as they flow.

The important difference between a power supply (like a battery) and the electroscope is that the power supply replenishes the charge on its terminals whenever it is depleted.

- Construct the simple circuit shown in Fig. 4.2. The "-" sign on the power supply indicates that there is a surplus of negative charge at that terminal.

- When the power supply is turned on, the lightbulb is illuminated, indicating that electrons are flowing through the circuit.

Question #12: Draw a sketch like Fig. 4.2 and show the direction electrons flow through the wire. Why do they flow in this direction? (Hint: Think about the forces on the electrons.)

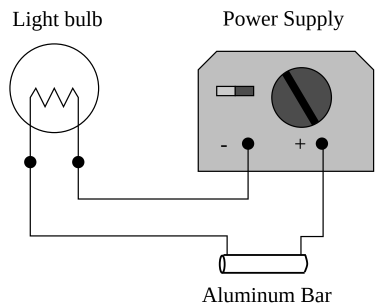

Figure 4.3: A more complicated electrical circuit.

Question #13: Describe what happens if you insert a piece of aluminum into the circuit? (See Fig. 4.3) What about a piece of wood? What about some of the other materials you looked at earlier?

4.6 Summary & Conclusions

Summarize briefly what this lab demonstrated. Think about the following questions: What makes electrical charges move? What factors affect how much charge moves? Why is the concept of resistance useful for describing this?

Question #14: Different materials have different electrical properties. For example, glass is an insulator, and aluminum is a conductor. Is it (a) because they contain different numbers of electrons or (b) because the electrons move more freely in some materials than others? Is there any evidence from this lab you can use to support your answer?

Chapter 5

Electrical Resistance, Power and Energy

5.1 Objectives

1. To become familiar with three basic concepts of electricity: voltage, current, and resistance.

2. To understand the relationship between energy and voltage.

3. To understand the relationship between energy and power.

5.2 A Glossary of Terms

The most important concepts related to circuits are reviewed here.

1. The **electron current** is the rate at which electrons flow through the wire. Current is measured in *Amperes* (often shortened to "amps") and

   1 Ampere = 1 (Coulomb of electrons)/second = 6.25×10^{18}electrons/second.

   The usual symbol for current is I. The electron current flows out of the "-" terminal and into the "+" terminal.

2. The **Voltage** of the power supply is a measure of the energy given to each electron. The unit of voltage is the volt (V) and

   $$1V = 1 \text{ Joule/(Coulomb of electrons)}.$$

   This means that each Coulomb of electrons which leaves the power supply takes with it 1 Joule of energy. The usual symbol for voltage is V.

3. The **voltage drop** across an object (such as a resistor, a lightbulb, or a motor) is the energy released by each Coulomb of electrons passing through the object. A voltage drop of 1V across a resistor means that 1 Coulomb of electrons deposits 1 Joule of energy in the resistor. In this lab, the voltage of the power supply and the voltage drop across the different objects studied are almost the same.

4. The **resistance** of an object is measured in Ohms (symbol Ω). It describes how hard it is to push a current through an object. A 1 Ω resistor requires 1 V to push 1 ampere through it. In other words: $1\,\Omega = 1$ Volt/Ampere.

5. **Ohm's Law** describes a relationship between the voltage drop across an object, the current through the object, and the resistance of the object. It is

$$V = IR \qquad \text{or} \qquad R = V/I$$

   where R is the resistance. In certain materials, R is a constant independent of V or I. These are called "Ohmic" materials.

6. **Power** is the amount of energy transformed from one type to another type every second. For example, a 1 MegaWatt hydroelectric dam converts 1 MegaJoule (1 million Joules) of gravitational energy (stored in the water behind the dam) into electrical energy every second. A 2000 W hairdryer converts 2000 J of electrical energy to thermal energy every second. In an electrical circuit, the power produced by a power supply is

$$\begin{aligned} \text{Power produced} &= \text{(energy given to each Coulomb of electrons)} \\ &\quad \times\text{(number of Coulombs leaving the power supply each second).} \end{aligned}$$

   We can write this as

$$P = VI.$$

5.3 Building the Circuit

Figure 5.1 shows how the wires must be connected in order for one multimeter to measure the *voltage* across the sample (we use the term *sample* to refer to the resistor, the lightbulb, or the diode as appropriate) and the the second multimeter to measure the *current* through the sample.

- Trace (on the diagram) the path taken by the electrons through this part of the circuit. Recall that electrons leave the "-" terminal and return through the "+" terminal. Also, note that the resistance of the voltmeter is so high that almost no current passes through it.

- This part of the circuit should already be set up. You should check that the wires are connected correctly by comparing with Fig. 5.1. Hints:

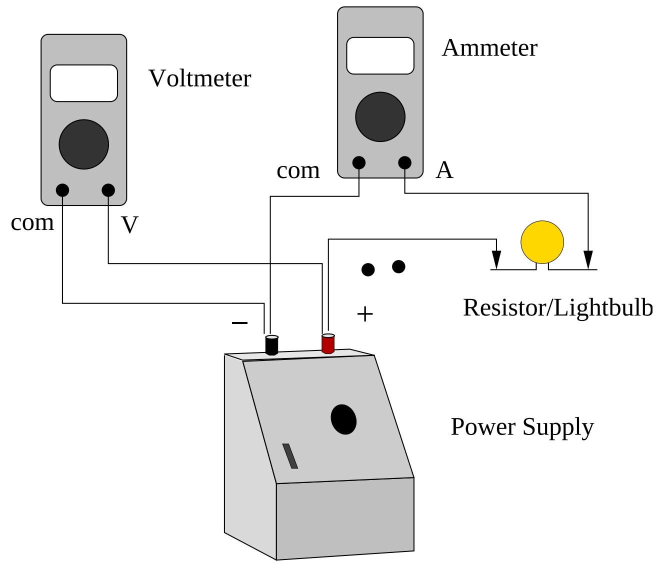

Figure 5.1: Circuit diagram showing how the voltmeter and ammeter are connected to the power supply.

1. When checking wire connections, don't follow the wires. It is much simpler to check that the *ends* of the wires are attached to the proper places in the circuit.
2. It doesn't matter whether the voltmeter is connected to the wires (as shown in the figure for simplicity) or directly to the power supply because nothing happens to the electrons between these two points.

- Check the multimeter scales. The ammeter has settings ranging from μA (microamperes) to A (amperes). These settings determine the range of the scale, and you will need to adjust these during the lab. Initially, you will want to use the 200 mA scale.
- Similarly, the voltmeter has settings ranging from mV (millivolts) to 200 V. In this lab, you will not go much above 5 V on the power supply, so you will want to adjust the scale on the multimeter accordingly.
- Disconnect the power supply from the breadboard, and turn the multimeters on. Turn the voltage knob on the power supply to "zero". Then turn the power supply on.
- Turn the ammeter and the voltmeter on. Make sure they are set to "dc" and not "ac".
- As you slowly turn the voltage knob up, the voltmeter should register the voltage produced by the power supply. The ammeter should read

zero since no current can flow when the circuit is disconnected from the breadboard.

- If this isn't what you observe, either (a) the multimeters are not set correctly to measure amperes or volts or (b) the wires aren't connected properly. Your TA can help you correct this.

5.4 The Measuring the Samples

5.4.1 The resistor

In this section we measure the current through a 100 Ω resistor as a function of applied voltage.

- Make sure the power is off.
- Connect the resistor to the power supply, as shown in Fig. 5.1.
- For the first part of the lab, the sample will be a 100 Ω resistor.
- Turn the power supply to its minimum voltage.
- Increase the voltage to a small value, for example, near 0.5 V (it doesn't have to be exactly 0.5 V, anything close is good enough).
- Record the voltage and the current in a table like the one below.

Table 1: Current-voltage characteristics of a 100 Ω resistor

V (Volts)	I (mA)	I (A)	R (Ω)

- Make a series of at least eight measurements over the whole voltage range (up to 5 V), and record your results. In the third column of the table, convert the measured currents from mA (milliamps) to A (Amps). Recall that $1\text{mA} = 10^{-3}\text{A}$.
- Use Ohm's law to find the resistance of the resistor at each value of the voltage.

Question #1: How does the resistance depend on the voltage?

Question #2: How does the measured resistance compare with the resistance marked on the resistor (100 Ohms).

Question #3: Describe how the temperature of the resistor changes as you increase the voltage.

Question #4: What is the main energy transformation which occurs in a resistor?

Question #5: How much power is transformed by the resistor at 1V? At 2V? At 3V?

Question #6: How long would it take for the resistor to lose 100 J of energy at 2V?

5.4.2 The lightbulb

In this section we measure the current through a lightbulb as a function of applied voltage.

- Turn the power supply off, and then turn the voltage to its minimum setting.

- Remove the resistor from the circuit, and replace it with the lightbulb.
- Turn the power supply on and make a table like the one shown below of the voltage and current for at least eight different points.

Table 2: Current-voltage characteristics of a lightbulb

V (Volts)	I (mA)	I (A)	R (Ω)

Question #7: Is the lightbulb ohmic? Why or why not?

Question #8: Describe how the resistance of the lightbulb changes with voltage.

Question #9: What are the main transformations of energy which occur in a lightbulb. Describe how you determine this (ie. what is the evidence?).

Question #10: How much power is transformed at 1V? At 2V? At 4V?

5.5 How much is a lot?

Question #11: If you climb a flight of stairs then your gravitational energy increases by (your mass in kg $\times$ height of stairs in m $\times$ 10m/s/s). Your mass is (your weight in pounds)/2.2. Estimate how much energy it takes to climb a flight of stairs.

Question #12: How long could you run a 100 W lightbulb for with this much energy?

Question #13: How long could you run a 1400 W hairdryer for with this much energy?

Question #14: When we talk about how many calories food has, we actually mean kilocalories (thousands of calories). A typical person might eat 1500 kilocalories worth of food during a day. 1 kilocalorie = 4.18×10^3 Joules. In an adult, most of this energy is ultimately transformed into thermal energy. How many Watts of power does a typical adult produce? In other words, how many Joules per second does a person transform? How does this compare to a lightbulb?

5.6 Summary & Conclusions

Summarize your findings by answering the following questions (in your own words).

1. What is resistance? How does it affect how much current flows in a circuit? Give an example from the lab.
2. What is voltage? How does it affect how much current flows in a circuit? Give an example from the lab.
3. What is current? Is it similar to the current in a river? If so, why?
4. What is the relationship between energy and voltage? Give an example from the lab.
5. What is the difference between energy and power? How are they related?

Question #15: [**Bonus Question**] Water sits behind a dam on a river. A small amount of water flows through a pipe and turns a turbine (which then produces electricity). In what ways is this similar to the electrical circuit? What plays the role of the power supply? What plays the role of the resistor or light bulb? In what units would you measure the current? What is the analogy to voltage?

Chapter 6

Electromagnetism

6.1 Objective:

The purpose of this lab is to understand the relationship between magnetism and electricity. Specifically

1. To study one useful consequence of the fact that electric currents produce magnetic fields.
2. To understand the circumstances under which a magnet can produce a current in a wire.
3. To test a simple theory of magnetic induction.

6.2 The Electric Motor

- Figure 6.1 is a schematic diagram labelling the main parts of the electric motor you will use in this lab.
- Remove the armature from the motor and study it carefully. The goal of the following exercise is to understand how electrical currents flow through the armature.
- Compare Fig. 6.2(a), which shows the armature and the connections between the coils and the split-ring commutator, with the armature. Make sure you understand how the wires shown in the figure correspond to the connections on the real armature.

Question #1: Imagine a power supply is attached to the armature so that current flows into one half of the split ring, and current flows out of the other half of the split ring. Note that the two halves of the split ring are insulated from each other. If the current flows as indicated by the dashed lines in Fig. 6.2(a),

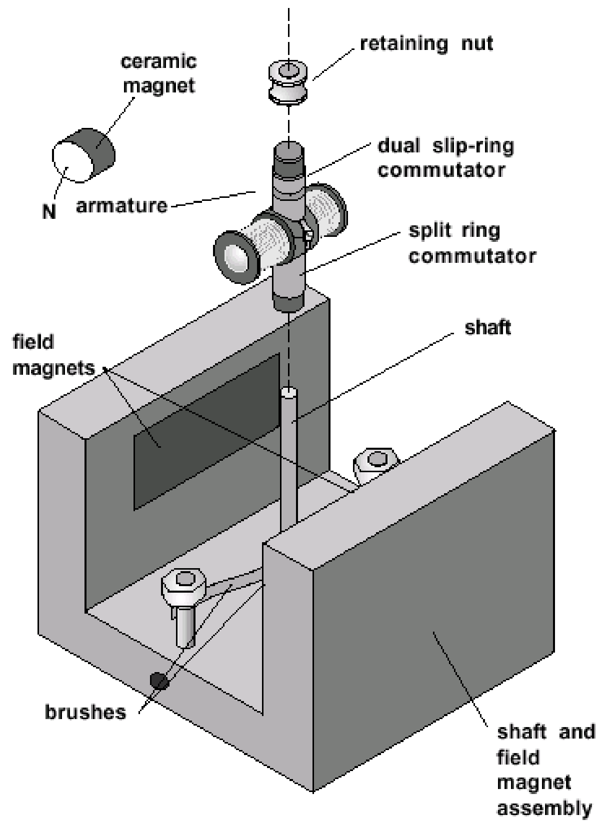

Figure 6.1: The motor

will point "A" be north or south? What about "B". You need the left-hand rule for coils to answer this. *You can indicate this on the figure.*

Question #2: Assuming that current flows as indicated in Fig. 6.2(a), draw arrows showing the forces on the armature in Fig. 6.2(b).

Question #3: Describe the motion of the armature in Fig. 6.2(b), assuming that the armature pivots freely. At what point does the armature stop moving?

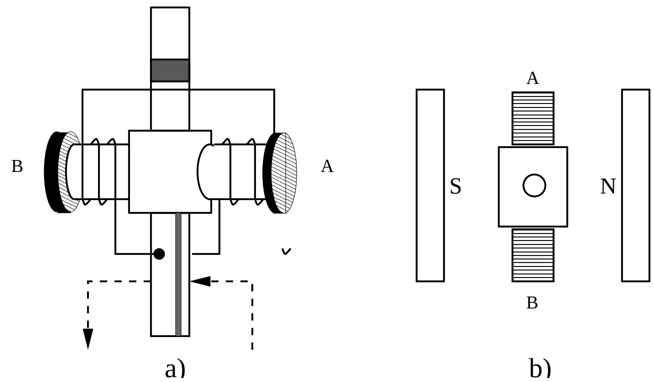

Figure 6.2: The armature

Question #4: Is this a useful motor? Explain your reasoning.

> **Caution!** Be careful not to overheat the motor. Do not use the power supply with the voltage setting above 4.5 V. If the coils on the armature become warm to the touch, turn the power off and allow the armature to cool before continuing.

- Put the armature back onto the shaft so that the split-ring commutators are in contact with the copper brushes. Even with the power off, you will notice that the armature prefers to point towards the fixed magnets. This is because the coils are wrapped around an iron bar.

Question #5: What is the role of the brushes?

Question #6: Rotate the armature by hand. At what points will the direction of the current in the armature change?

Question #7: Draw two pictures similar to Fig. 6.2(b) showing (i) how the poles of the electromagnet change as the armature rotates and (ii) how the forces on the electromagnet change as the armature rotates.

Question #8: From the previous question, what kind of motion would you predict for the armature?

- Make sure the power supply is off.
- Connect the motor to the power supply, set the voltage to 3 V, and turn the power on. You will probably need to start the motor with a push of your finger.

Question #9: Does the motion of the armature match your prediction? If not, why not?

Question #10: Once the motor is connected to the power supply, does it have a preferred direction to turn? What happens if you reverse the direction of the current?

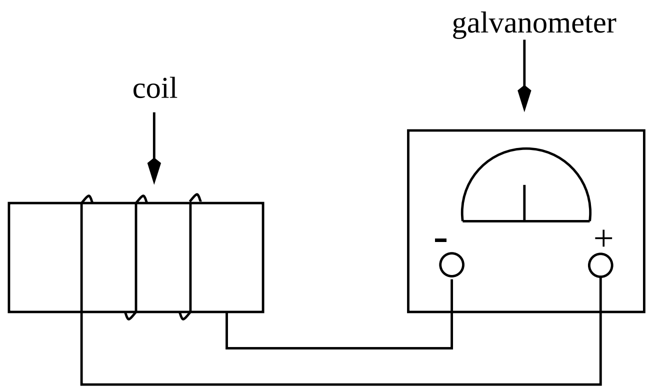

Figure 6.3: The coil and the galvanometer

Question #11: What happens if you increase the voltage to 4.5 V? Explain why in terms of (a) how the current through the coils changes, (b) how the magnetic fields produced by the coils changes, and (c) how the forces on the armature change.

Question #12: What is the energy transformation which takes place when the electromagnet moves?

6.3 Current Generation by a Magnetic Field

6.3.1 The magnet, the coil, and the galvanometer

- Connect the 800-turn coil to the galvanometer as shown in Fig. 6.3. A **Galvanometer** is a device for measuring electrical currents. Notice that the current is measured in microAmps (μA) and that it can be negative. The sign of the current indicates its direction.
- Bring the north pole of a bar magnet close to the end of the coil. The galvanometer needle should move. If the needle doesn't move, check that the circuit is connected correctly. By experimenting with the bar-magnet and coil, answer the following questions. In each case, describe (in one or two sentences) the experiment you did to answer the question.

Question #13: Carefully describe the motion of the galvanometer needle as you bring the magnet close to the end of the coil, starting far away.

Question #14: What kind of motion produces the largest deflection of the galvanometer needle?

Hypothesis 2 *Consider a magnet which starts a distance d_1 away from the coil. If the magnet is moved to a distance d_2 in a time t then the current generated in the coil is ($\propto$ means "proportional to")*

$$\mathit{Current} \propto \frac{d_1 - d_2}{t}.$$

- This hypothesis is not completely correct. It does contain some elements of truth, however. You will be asked to determine its strengths and weaknesses.

Question #15: According to Hypothesis 2, what will be the current if the magnet is stationary? Why? Do an experiment to test this.

Question #16: According to the hypothesis, how does the current depend on the speed of the magnet? Is this supported by your observations? Don't forget to describe the experiment you perform.

Question #17: According to the hypothesis, what is the difference between moving the magnet *towards* the coil ($d_1 > d_2$) and moving the magnet *away from* the coil ($d_1 < d_2$)? What do you observe?

Question #18: According to the hypothesis, moving the magnet towards the coil at 5 cm/s produces the same current no matter how far away the magnet is from the coil. Is this what you find?

Question #19: According to the hypothesis, does it matter which end of the coil you approach with the magnet? What do you observe? What if you approach from the side?

Question #20: According to Hypothesis 2, does it matter which pole of the magnet is closest to the coil? Does it matter in practice?

6.4 Summary & Conclusions

Write a brief summary of your findings. Make sure you discuss each of the objectives (For example "A useful consequence of the fact that electric currents produce magnetic fields is…").

Also, make sure you answer the question "Is Hypothesis 2 a good theory?"

Question #21: Can you suggest an improvement to Hypothesis 2 which will do a better job of explaining your experiments?

Chapter 7

Quantum Mechanics I: Atomic Spectra

Caution! *The fluorescent gas tubes used in this lab are delicate, and become very hot during use. Be careful when you handle them. The fluorescent gas tubes in this lab may contain mercury. Mercury is poisonous. If you break a gas tube, notify your TA immediately.*

7.1 Objectives

1. To compare the spectra of a tungsten filament, a fluorescent light tube, and hydrogen tube with each other.
2. To study two different theories of light emission.

7.2 The spectroscope and the visible spectrum

- A sketch of the spectroscope is shown in Fig. 7.1(a). The eyepiece contains a *diffraction grating* which breaks light up into its constituent colours. Use the spectroscope to look at an *incandescent* light bulb. The colours in the light emitted by the bulb will appear to be superimposed on a scale, as shown in Fig. 7.1(b). The scale tells you the wavelength of the light in hundreds of nanometers (nm). Recall that 10^9 nm is 1 m.

Question #1: Make a table like the one shown below

Table 1: Spectrum of the Incandescent Bulb

Color	Approx. Range of Wavelengths (nm)	Brightness

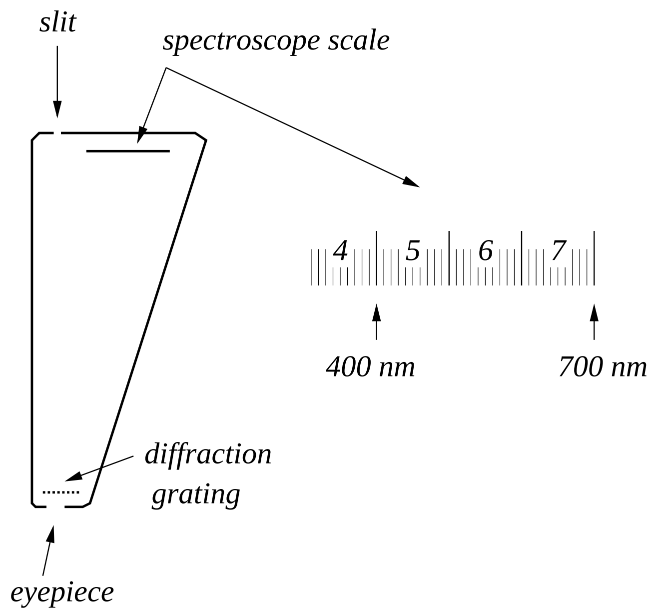

Figure 7.1: Spectroscope and spectroscope scale.

Use this table to record what you see when you look at the spectrum of the incandescent bulb. In the table, indicate the colours you see, and their wavelengths and relative brightness.

Question #2: What colour has the longest wavelength? What colour has the shortest wavelength? What colours are the brightest and dimmest?

Question #3: Why do you think the spectrum cuts off beyond certain wavelengths? Does it mean that the lightbulb only produces the colours you see?

Question #4: Light with wavelengths shorter than about 400 nm is called "ultraviolet", and light with wavelengths longer than about 650 nm is called "infrared". Why is this?

Question #5: The relationship between wavelength and frequency is

$$f = \frac{c}{\lambda} \qquad \text{or} \qquad \lambda = \frac{c}{f}$$

where c is the speed of light, λ (the Greek letter "lambda") is the wavelength *measured in metres* and f is the frequency in Hertz (Hz). The speed of light is $c = 3 \times 10^8$ m/s. What is a typical frequency of red light? What is a typical frequency of violet light? Show your calculation.

Question #6: What aspects of spectrum of the light bulb does Hypothesis 1 in the pre-lab describe correctly? Are there any predictions it makes which are incorrect?

7.3 Spectra of Gases

- Use the spectroscope to study the spectrum of one of the overhead fluorescent lights.

- Now use the spectroscope to study the spectrum of hydrogen.

Question #7: Describe the two spectra carefully. How do they compare with each other and with the spectrum of the incandescent light bulb?

Question #8: Can your observations be explained in terms of random motion of electrons in the gas tubes? Why or why not? (Think carefully about this question when you write your conclusions at the end of the lab).

7.4 Measuring Spectra

7.4.1 Calibrating the Spectroscope

- The scale in the spectroscope is not very accurate, so it needs to be compared to a known source.
- Look at the hydrogen tube with the spectroscope and measure the wavelengths of the lines. Notice that the wavelengths depend on how you hold the tube. You will need to experiment to find the best way to do the measurement, and then do it the same way from now on.
- Complete the table below:

Calibration Data

Measured λ (nm)	Actual λ (from chart) (nm)	Actual−Measured (correction) (nm)

The *correction* is the difference between the actual λ and the measured λ.

- Be sure to note whether the measurements are too low or too high.
- Be sure to not whether the correction is biggest at red wavelengths or at violet wavelengths.

7.4.2 Measuring Unknown Gases

- There are several unknown tubes provided. For each tube, make a table like the one below.

Spectrum of Tube #1

Colour	Brightness	Measured λ (nm)	Estimated Corrected λ (nm)

- You can correct your measured λ by adding a correction. You need to estimate the correction by looking at your table of calibration data.

Question #9: Compare your spectra with the wall chart. What are the unknown gases?

7.5 Bohr's atomic model and Plack's constant

Neils Bohr proposed a *quantum theory* of light emission from atoms. You will learn more about this theory in class. For now, all you need to know is:

Hypothesis 3 *According to Bohr's theory, the gas tube is produces light at only certain specific frequencies. The allowed frequencies are:*

$$f = Z \times (3.29 \times 10^{15}) \left[\frac{1}{n^2} - \frac{1}{m^2} \right]$$

where Z is the number of protons in the nucleus of the gas atom ($Z = 1$ for hydrogen, $Z = 2$ for helium, and so on). The numbers n and m can be $1, 2, 3 \ldots$ and we only consider $m > n$.

Question #10: Complete the table below using Bohr's formula for the predicted spectrum of hydrogen. Note that you are only calculating a small fraction of the possible frequencies.

m	n	f (Hz)	λ (m)	λ (nm)
3	1			
3	2			
4	2			
5	2			

Question #11: Which of the wavelengths you just calculated are visible?

Question #12: How well do your calculated lines compare with the spectrum you measured.

7.6 Summary & Conclusions

Go back and look at the objectives for this lab. Write a brief summary of your findings, making sure you address the issues raised in the objectives. Remember: you studied two hypotheses for light emission. How well did they work? How are they different? What things do they get right? What things do they get wrong? Could either of the theories be used to explain both the tungsten filament *and* the hydrogen gas tube?

Question #13: [**Bonus Question**] Now consider helium ($Z = 2$). Calculate the wavelength of light produced in the transition of an electron from $n = 4$ to $n = 3$. Show your calculations clearly. How does the calculated wavelength compare with the spectrum on the wall chart.

Chapter 8

Quantum Mechanics II: Radioactivity

Caution: *Liquid nitrogen is extremely cold and can cause severe damage if it makes prolonged contact with skin. Spills are especially dangerous if the nitrogen soaks into clothing.*

8.1 Objective

1. To study background radiation.
2. To determine the kinds of radiation emmitted from a lead-210 sample.
3. To determine the levels of the various kinds of radiation emitted by the lead-210 sample.

8.2 Radiation

8.2.1 Kinds of radiation

- Alpha (α) particles: Very large nuclei may spontaneously emit an alpha particle. For example, Americium, which is near the bottom of the periodic table, decays this way. The α-particle is a helium (He) nucleus consisting of two protons and two neutrons. It is therefore *positively* charged. α-particles, which are relatively heavy, will produce straight dense trails in a cloud chamber. α-particles have a range of less than 8 cm in air, and can be stopped by a piece of paper.

- Beta (β) particles: If a nucleus has too many neutrons the most likely form of radioactive decay will be the emission of an electron from the nucleus. These high-energy electrons are known as beta particles. The β-particle is formed by the instant transformation of a neutron into a proton plus an energetic electron which then escapes from the nucleus. β-particles are light and leave wispy, irregular trails. β-particles have a typical range of 10–10000 cm in air, and 0.01-10 cm in water, depending on how fast they are travelling. β-particles are *negatively* charged.

- Gamma (γ) rays: After each of the previous types of radioactive decay the new nucleus will have an excess of energy and this is usually released by the emission of one or more gamma-rays . γ-rays are electromagnetic radiation similar to radio waves, visible light, and X-rays, except that they have a much higher frequency (or shorter wavelength). γ-rays will penetrate to great depths in materials, and no amount of absorber will completely stop all of the gamma radiation . What is usually done in practice is to use sufficient thickness of an absorber to reduce the radiation level to an acceptable value. γ-rays have *no* charge, and are difficult to see in a cloud chamber.

- Cosmic rays: When there is no radiation source, cosmic rays may enter the chamber, producing thin misty trails. Cosmic rays are extremely energetic particles, primarily protons, which originate in the sun, other stars and some of the violent events which occur in space. The cosmic ray particles interact with the upper atmosphere of the earth and produce showers of lower energy particles. Many of these lower energy particles are absorbed by the earths' atmosphere as they travel down to the surface. At sea level the cosmic radiation is composed mainly of muons, with some gamma-rays, neutrons and electrons. As cosmic rays bounce off other particles in the cloud chamber, they produce "curly" or jagged tracks.

8.3 The Geiger Counter

The Geiger counter is a sensitive tool for measuring β- and γ-rays (α-rays cannot penetrate the glass case of the detection tube). The Geiger counters used in this lab emit an audible "click" when they detect a radioactive particle. These particular Geiger counters only operate when you push the button on their front.

Question #1: Radiation is detected in a sensitive "detection tube" which is, in this case, the gold-coloured tube embedded in the side of the Geiger counter. Measure the dimensions of the detection tube and calculate the cross sectional area of the tube in cm^2.

Question #2: Measure the background radiation of the room. State how you measured the radiation level, and give the value. The simplest measurement is to count the number of clicks (or *counts*) over some time interval. Convert the amount of radiation you measure into the amount of radiation per cm^2 per second (ie. $\text{counts/cm}^2\text{s}$).

Question #3: Estimate your cross-sectional surface area in cm^2 (describe how you make this estimate). From this, how much radiation is passing through your body per second?

Question #4: Now take the Geiger counter outside and measure the background radiation. How many $\text{counts/cm}^2\text{s}$ do you measure outside? Is it different from inside? Why do you think this is?

Question #5: Based on differences between radiation levels inside and outside, where do you think the background radiation is coming from?

Question #6: Hold the radioactive source a few cm away from the detection tube (the gold-coloured tube) in the Geiger counter. How does the radiation level compare with the background radiation? How far do you have to move away from the source before the radiation is indistinguishable from the background?

Question #7: Give two reasons why the radiation measured by the Geiger counter drops as you move the source away.

- Hold the radioactive source a few cm away from the detection tube (measure and the distance). Record the distance. Now measure and record the level of radiation from the source, using the same method as you used to measure the background radiation.

- Now hold the source *behind* the Geiger counter, so that the radiation must travel through the black case to reach the detection tube. Make sure the distance to the detection tube is the same as above. Now measure and record the radiation level. Don't forget to mention the time interval you measure over.

- Make a table like the one below

Source position	# of counts	# of counts (background subtracted)	Source radiation level (counts/cm^{2}s)
In Front			
Behind			

- In the first column, record the total number of counts you detect. In the second column, subtract the number of counts which can be attributed to background radiation. In the final column, determine the radiation level measured by the detector.

Question #8: When the detection tube is visible to the radioactive source, both β- and γ-rays are detected (along with the background), but when the source is behind the Geiger counter β-rays are screened by the black case and only γ-rays (and the background radiation) are detected. What are the levels of β- and γ-radiation you measured from the source?

Question #9: Obviously, the number you get in the previous question is going to depend on how far the detector is from the source. You can estimate the *total* radiation of each kind (in units of counts/second) emitted by the source by assuming that the radiation is spread out evenly over the surface of a sphere. If the detector was d cm from the source in your experiment, then the total radiation passing through an imaginary spherical shell enclosing the source is

$$\text{total radiation} \left[\frac{\text{counts}}{\text{second}}\right] = \text{measured radiation} \left[\frac{\text{counts}}{\text{cm}^2 \text{ second}}\right] \times 4\pi d^2 [\text{cm}^2].$$

Estimate the total radiation levels of β- and γ-rays produced by your source.

Question #10: By counting the number of "clicks", you learn something about radiation levels in the room. This isn't the whole story though. Counting "clicks" doesn't say anything, for example, about whether the radiation is dangerous. What other information would be useful to know about the radiation? Hint: You know that radiation is just another name for "fast-moving particles". If the particles were bigger (for example, baseball sized) what kinds of things would determine whether they were dangerous?

Question #11: Write down the equation for the β-decay of ^{210}Pb (Lead-210). What is the isotope which is produced in this reaction?

Question #12: The β-particle is a fast moving electron and has kinetic energy. The γ-ray carries radiant energy. Where does this energy come from?

8.4 The Cloud Chamber

8.4.1 Operating the cloud chamber

Making the cloud chamber work properly is not easy. You will need to spend time experimenting to establish the best operating conditions. If you are having trouble seeing anything, be patient.

- Place the green blotter paper and black cardboard disk into the cloud chamber. Make sure the hole in the side of the cloud chamber is not blocked by the blotter paper.
- Soak the green blotter paper and black cardboard disk with alcohol. Be generous with the alcohold, but do not add so much alcohol that a pool forms at the bottom. Put the lid on the cloud chamber.
- A radioactive source is provided, mounted on a cork. Insert the cork into the hole in the side of the chamber, so that the source is inside.
- Place the aluminum stand in the center of the styrofoam dish. Fill the dish about half-way with liquid nitrogen. Liquid nitrogen will be given to you by the TA.
- Place the cloud chamber on the aluminum stand. Illuminate the interior of the cloud chamber through the side window with the light source.
- Now watch the cloud chamber carefully. Nothing will happen for several minutes. As the chamber cools, you will start to see tracks left by passing radiation. The number of tracks you see will depend on how well you have optimized operating conditions.

8.4.2 Optimizing the operating conditions

To optimize the chamber properly, you should know a little bit about how it works. When a subatomic particle (radiation) travels through the chamber, it collides with air molecules, producing free ions. Alcohol vapor in the chamber condenses around these free ions, forming droplets. The droplets are what form the trail. Ideally,

1. the alcohol-soaked blotting paper should be warm to produce lots of vapor,
2. one other surface (in this case the base) should be cold.

The cold surface produces a layer of cold air. Alcohol vapor in the cold air layer wants to condense to form clouds, but needs something—in this case, the free ions—to "seed" or "nucleate" the condensation.

What can go wrong?

- The chamber is too warm. In this case, the alcohol vapor doesn't want to condense. No tracks are seen.
- The chamber is too cold. In this case, the alcohol vapor condenses too easily, and forms fog. If this happens, take the cloud chamber off the aluminum block for awhile.
- The blotting paper is too cold. In this case, no alcohol vapor is produced. Again, take the cloud chamber off the aluminum block.
- *The most common problem is that the cloud chamber becomes too cold. Remember that the aluminum block takes a long time to cool down, but will also keep the chamber cold for a long time. It is not necessary to add more liquid nitrogen immediately after you run out!*
- Once you have learned how to operate the cloud chamber, answer the following questions:

Question #13: Describe the different kinds of radiation tracks you see. Where do the tracks come from? Do they all come from the same place? Which kinds do you see most often?

Question #14: Read the descriptions of the different kinds of radiation at the beginning of this lab. Based on your observations, what kinds of radiation are you observing in the cloud chamber? Is this consistent with your Geiger counter measurements?

Question #15: Compare the radiation levels you see in your cloud chamber with your earlier estimate of the radiation produced by the source. Do you expect these numbers to be the same? Why?

Question #16: Take the source out of the cloud chamber. Describe the radiation tracks you observe. What kind of radiation are you seeing?

8.5 Summary & Conclusions

Summarize your findings, remembering to address issues raised in the objectives.