Observational Experiments

1 What are they?

An observational experiment is an experiment that students perform when they are investigating a new phenomenon. Thus, they do not make predictions or have expectations about its outcome. Students need to collect data, analyze them and find a pattern in the data. They then need to explain the reasons for the pattern (if applicable), and/or construct a qualitative or quantitative relationship.

2 Why do you want to use them?

Observational experiments have the following desirable features:

- Concrete experiences
  These experiments provide concrete experiences as part of the learning cycle.
- Open-mindedness
  Students learn to learn to approach data without knowing whether they are right or wrong.
- Decision-making
  Students learn to make decisions about representing data, considering outliers, deciding what pattern they want to look for.
- Epistemic cognition
  Students learn to deal with situations when there is no right answer. They learn how to choose a productive way to investigate complex phenomena.
- Real data
  Students learn to deal with the complexities of real data.

3 How and where do you use them?

Observational experiments can be used in the following contexts:

- In a lecture while developing ideas in a new topic.
  The instructor performs the experiment, students record data, decide what variables are important, and try to find patterns in the data by plotting graphs.
- In the lecture, laboratory or recitation/workshop.
  The data from such experiments (performed by someone else) are provided. Students analyze them and look for patterns.
- In the lecture, laboratory or recitation/workshop.
  The data and analysis are provided. Students construct explanations for the trends in the data.

- In the laboratory. Students perform these experiments in the lab (before learning about them in lecture), collect and analyze data, find patterns, and construct explanations or mathematical relationships to describe the patterns.
- As a homework problem. Data for an experiment are provided and students are asked to analyze the data and find patterns in them.

4 What are some types

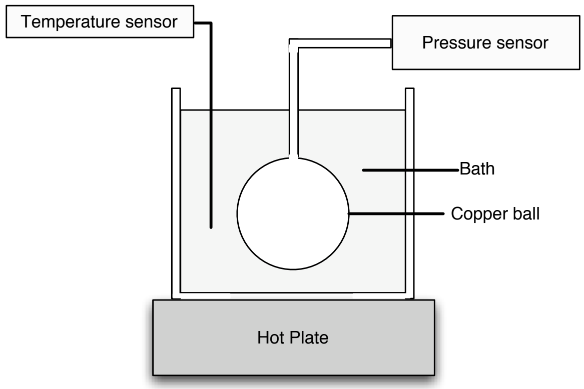
Observational experiments can be used to introduce any new area of physics. They can be either qualitative or quantitative. As described in the previous section, some or all parts of an observational experiment can be used for example, students can collect and analyze data, and/or find patterns, and/or construct explanations.

5 How do you score them?

We present an example of an observational experiment, a model solution and an example of student work. After this we present the rubrics we use, the scores on various abilities, and reasons as to why particular scores were given.

Sample design task:
You have a sealed hollow metal sphere with an unknown gas inside. You also have a thermometer, a pressure gauge, a hot plate, some ice and a container containing water. Design an experiment to determine if there is a relationship between pressure and temperature of the unknown gas when its volume is kept constant.
The metal sphere can be submerged in the container of water such that the water provides a temperature bath for the sphere and its contents. Use the ice and the hot plate to construct baths at different temperatures.
Write in your report :

a) Describe your experimental design with a labeled diagram. Include how will you vary and measure the pressure and temperature.
b) What assumptions are you making in your design?
c) Mention what the independent and dependent variables are.
d) What are sources of experimental uncertainty and how can you minimize them?
e) Record your observations in an appropriate format. Make a table and a graph if necessary.
f) Use Excel to analyze and find a best-fit function for your data.
g) What pattern did you find from your observations? Write a verbal description and a mathematical relationship.



(h) Describe what happens to the gas microscopically as the water in the bath becomes warmer.

(i) Based on the relationship you developed in g), can you consider the gas in the sphere as an ideal gas? Explain why or why not.

(j) Draw a graphical representation of the process using the P and T, P and V and V and T axes as the water in the bath becomes warmer.

(k) Use this relationship to predict the value of the lowest temperature to which you can cool that this gas.

Model solution:

We will immerse the sealed metal sphere in a bath of ice. We will then slowly heat the bath using a hot plate. We will measure the temperature of the bath using a thermometer. We will try to ensure conditions of thermal equilibrium between the bath and the air inside the sphere: we stir the bath, we wait before measuring the temperature, the sphere is made of metal which is a good conductor. Thus we will assume that the temperature of the air in the sealed sphere is the same as the thermometer reading. The pressure of air is measured by the gauge attached to the sealed sphere.

Our data is shown below. We plot a graph of temperature (independent variable) versus pressure (dependent variable).

We can fit a straight line to the graph. This shows that there is a linear relationship between pressure (in mm of Hg) and temperature (in Celsius).

The graph does not pass through the origin. If we extend the graph towards lower temperatures, we see that it intersects the temperature axis with a negative intercept of ?273 C. At this point, the pressure is zero. From kinetic theory, pressure of a gas is related

Temperatue ($^{\circ}C$)	Pressure(mm Hg)
10	750
15	750
20	750
25	750
30	750
35	750
40	750
45	750
50	750
55	750
60	750
65	750
70	750
75	750
80	750
85	750
90	750
95	750

to the speed of the molecules. So, the lowest possible pressure is zero, which means the lowest possible temperature is ?273 C.

Sample student work:

Scores using rubrics:

Scientific Ability	0	1	2	3
Is able to design a reliable experiment that investigates the phenomenon.	The experiment does not investigate the phenomenon.	The experiment involves the phenomenon but due to the nature of the design it is likely the data will not contain any interesting patterns.	The experiment investigates the phenomenon and it is likely the data will contain interesting patterns, but due to the nature of the design some features of the patterns will not be observable.	The experiment investigates the phenomenon and there is a high likelihood the data will contain interesting patterns. All features of the patterns have a high likelihood of being observable.

SCORE: 3. The experiment clearly investigates the phenomenon.

Scientific Ability	0	1	2	3
Is able to decide what is to be measured and identify independent and dependent variables.	The chosen measurements will not produce data that can be used to achieve the goals of the experiment.	The chosen measurements will produce data that can be used at best to partially achieve the goals of the experiment.	The chosen measurements will produce data that can be used to achieve the goals of the experiment. However, independent and dependent variables are not clearly distinguished.	The chosen measurements will produce data that can be used to achieve the goals of the experiment. Independent and dependent variables are clearly distinguished.

SCORE: 3.

Scientific Ability	0	1	2	3
Is able to use available equipment to make measurements	At least one of the chosen measurements cannot be made with the available equipment.	All chosen measurements can be made, but no details are given about how it is done.	All chosen measurements can be made, but the details of how it is done are vague or incomplete.	All chosen measurements can be made and all details of how it is done are clearly provided.

SCORE: 3. The chosen measurements can be made with the given equipment. The diagram and the description clearly mention how and where the measurements are done.

The student mentions where to place the thermometer.

Scientific Ability	0	1	2	3
Is able to describe what is observed without trying to explain	No description is mentioned.	A description is mentioned but it is incomplete. Or, most of the observations are mentioned in the context of prior knowledge.	A description exists, but it is mixed up with explanations or other elements of the experiment. Or some observations are mentioned in the context of prior knowledge.	Clearly describes what happens in the experiments.

SCORE: 2. The student starts (in part g) describing the pattern found (P proportional to T), but then uses the ideal gas equation (prior knowledge) to elaborate the details.

Scientific Ability	0	1	2	3
Is able to identify the shortcomings in an experimental design and suggest improvements.	No attempt is made to identify any shortcomings of the experimental design.	An attempt is made to identify shortcomings, but they are described vaguely and no suggestions for improvements are made.	Some shortcomings are identified and some improvements are suggested, but not all aspects of the design are considered.	All major shortcomings of the experiment are identified and specific suggestions for improvement are made.

SCORE: 0. No mention is made of shortcomings.

Scientific Ability	0	1	2	3
Is able to construct a mathematical (if applicable) relationship that represents a trend in data	No attempt is made to construct a relationship that represents a trend in the data.	An attempt is made, but the relationship does not represent the trend.	The relationship represents the trend but no analysis of how well it agrees with the data is included (if applicable), or some features of the relationship are missing.	The relationship represents the trend accurately and completely and an analysis of how well it agrees with the data is included (if applicable).

SCORE: 3.

Scientific Ability	0	1	2	3
Is able to identify the assumptions made in devising the explanation	No attempt is made to identify any assumptions.	An attempt is made to identify assumptions, but most are missing, described vaguely, or incorrect.	Most assumptions are correctly identified.	All assumptions are correctly identified.

SCORE: 3.

Scientific Ability	0	1	2	3
Is able to identify sources of experimental uncertainty	No attempt is made to identify experimental uncertainties.	An attempt is made to identify experimental uncertainties, but most are missing, described vaguely, or incorrect.	Most experimental uncertainties are correctly identified.	All experimental uncertainties are correctly identified.

SCORE: 3.

Scientific Ability	0	1	2	3
Is able to evaluate specifically how experimental uncertainties may affect the data	No attempt is made to evaluate experimental uncertainties.	An attempt is made to evaluate experimental uncertainties, but most are missing, described vaguely, or incorrect.	Most experimental uncertainties are evaluated correctly, though a few contain minor errors, inconsistencies, or omissions.	All experimental uncertainties are correctly evaluated.

SCORE: 0.

Scientific Ability	0	1	2	3
Is able to minimize experimental uncertainties.	No evidence of any effort to make precise measurements from video	Some evidence of an attempt to take precise measurements. Most major sources or uncertainty are ignored or poorly addressed	Evidence of effective data taking such as multiple measurements etc. One major omission or some small oversights	Precise data collection in all aspects afforded by the video. Attention to reducing all obvious sources of random and systematic uncertainty in data collection.

SCORE: 1. The student mentions that multiple trials must be done but there is no attempt to do so.

Scientific Ability	0	1	2	3
Is able to record and represent data in a meaningful way	Data are either absent or incomprehensible.	Some important data are absent or incomprehensible.	All important data are present, but recorded in a way that requires some effort to comprehend.	All important data are present, organized, and recorded clearly.

SCORE: 3.

Scientific Ability	0	1	2	3
Is able to analyze data appropriately	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed or inappropriate.	The analysis is appropriate but it contains minor errors or omissions.	The analysis is appropriate, complete, and correct.

SCORE: 2. A straight line is found as the best-fit line to the data but there is no mention of how good a fit the line is to the data (for example, the R-value is missing).

Scientific Ability	0	1	2	3
Is able to communicate the details of an experimental procedure clearly and completely	Diagrams are missing and/or experimental procedure is missing or extremely vague.	Diagrams are present but unclear and/or experimental procedure is present but important details are missing.	Diagrams and/or experimental procedure are present but with minor omissions or vague details.	Diagrams and/or experimental procedure are clear and complete.

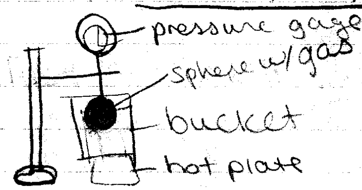
SCORE: 3.

11-17-04
Physics Lab

Lab 9: Gases

PV=nRT

A i)



First we will submerge gas sphere into bucket of ice water. Every 5°C the bucket H_2O, we will record the pressure and temperature.
Then we will take the bucket of water and warm it with the hot plate, while at the same time recording the pressure and temperature change of sphere of gas. every 5° the bucket H_2O goes up.
When measuring the temp. of the bucket H_2O, keep the thermometer close to sphere of gas to get most accurate reading.

b) Assumptions:
~~temp.~~ of bucket water is same as sphere of gas.
Assume thermometer and pressure gage are accurate.
~~Sphere is made of~~ a "good" metal, it is a good thermoconductor so sphere of gas reaches the same temperature as bucket H_2O.

c) Independent: Temperature
~~Dependent~~: Pressure

d) See attached graphs
e) Sources of Uncertainty - inaccurate measuring ~~devices~~ (pressure gauge & thermometer).
Minimize by using more accurate instruments, and multiple trials.

f) see graph

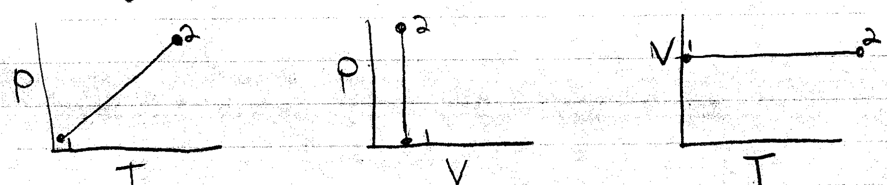
g) The pattern we observed was that as the temperature increased, the pressure increased this gives us the conclusion that temperature and pressure are directly proportional

$$PV = nRT$$

Because volume and # of moles (n) and R are constant, we can thus conclude mathematically that $P = T$.

h) As the temp of the bucket H_2O increases, so does the temp of the gas sphere, thus the gas molecules gain more energy and therefore move around at a quicker rate. The likelihood of collisions consequently increases as the molecules move around faster which increases pressure.

i) Based on g, you can conclude that the gas inside the sphere is not an ideal gas because the temperature and pressure are not exactly equal.

j) 

As H_2O in bucket gets warmer

k) $y = 2.8143x + 719.83$

$0 = 2.8143x + 719.83$

$\frac{-719.83}{2.8143} = x = -255.775859\ °C$ ← Lowest temp you could actually lower gas to.

T (C)	P (mm Hg)
17	760
22	780
27	790
32	810
37	820
42	835
47	850
52	865
57	880
62	890
67	905
72	920