Application Experiments

1 What are they?

An application experiment typically involves solving a practical problem or determining an unknown quantity by performing experiments. Students need to solve these experimental problems using at least two different methods and then compare the results. Often they need to perform additional experiments or make informed estimates to determine some physical quantities.

2 Why do you want to use them?

Application experiments have the following desirable features:

- Deal with realistic problems, not idealized.
  Application experiments are open-ended problems and could be ill-defined. They are more in tune with the kinds of activities practicing scientists pursue.
- Help students connect different ideas
  To solve a problem students usually need to use more than one idea, often from different physics topics.
- Develop decision-making abilities.
  Students need to make decisions about practical issues, such as, whether they can ignore a particular force in the problem. They also need to decide which assumptions might work, or fail in the given situation.
- Connection between physics and everyday life
  Most of the problems have practical applications and all of them use simple apparatus.

- Help students develop divergent thinking
  All problems require students to design at least two different experiments.
- Help students develop evaluation abilities
  Students need to explain the discrepancies between the results of two experiments.

3 How and where do you use them?

Application experiments are performed by students after an explanation of a phenomenon or a relationship between physical quantities has been well-established. A group of students can discuss possible methods of solving the problem, and decide which methods are more suitable. They perform at least two experiments to solve the task, and then compare the results.

Application experiments can be used in the following contexts:

- In a laboratory.
  Students are given an experimental task which they have to solve using ideas and relationships that have been developed earlier.
- As a laboratory practical exam.
  Students design an experiment to determine an unknown quantity.
- As a video problem.
  Some experimental problems have been videotaped (see the task titled "Video Problems"). Students can collect and analyze data from the two experiments in each video and determine an unknown physical quantity. These can be used in a laboratory or as homework assignments.

4 How do you score them?

We present an example of an application 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:
Design at least two independent experiments to determine the coefficient of static friction between your shoe and the sample of carpet/linoleum provided. Equipment: Spring scale, ruler, protractor, carpet or wood surface, tape.
Include in your report the following for each independent experiment:

a Draw a sketch of your experimental design.

b Write an outline of the procedure you will use.

c Decide what assumptions about the objects, interactions, and processes you need to make to solve a problem. How might these assumptions affect the result?

d Draw a free-body diagram for the shoe. Include an appropriate set of co-ordinate axes. Use the free-body diagram to devise the mathematical procedure to solve the problem.

e What are the possible sources of experimental uncertainty? How would these affect the result? How could you minimize them?

f Perform the experiment and record your observations in an appropriate format. What is the outcome of your experiment?

g When finished with both experiments, compare the two values you obtained for the coefficient of static friction. What are possible reasons for the difference?

h Suggest specific improvements in the experiments.

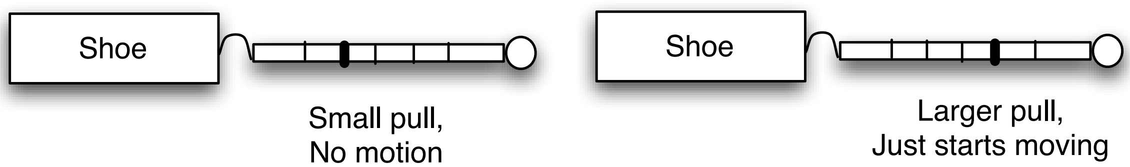
i Decide why this activity was included in the lab. Briefly describe two real life situations in which you need to figure out things similar to this experiment

Model solution:

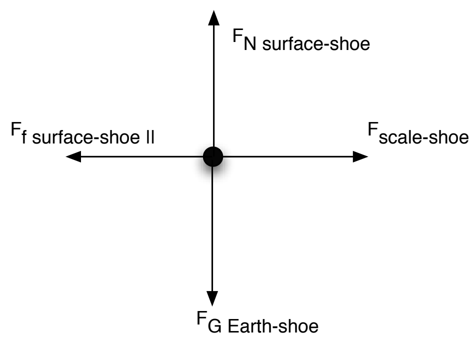
In both methods, we first estimate the maximum value of force of static friction between the shoe and the carpet.

<u>Method 1</u>

Place the shoe horizontally on the carpet. Attach the spring scale to the shoe and pull on the scale. The shoe does not move at first. Keep pulling the scale harder till th eshoe just begins to slide. The spring scale reading just before the shoe moved is the maximum force of static friction between the surfaces $\mathrm{F}^{\mathrm{max}}_{\mathrm{f\ surface-shoe}\ \|}$



The free-body diagram when the shoe just starts to move:



Applying Newton's 2nd law for the horizontal and vertical components, and use the relation between the normal force and the frictional force:

$$\begin{aligned} F_f^{max} - F_{scale-shoe} &= 0 \\ F_N - mg &= 0 \\ F_f^{max} &= \mu F_N \end{aligned}$$

We get $\mu = F_{scale-shoe}/mg$.

We use the scale to measure the mass of the shoe, the spring scale reading gives $F_{spring-shoe}$

Assumptions:
The shoe does not rotate when it is pulled – we are treating it as a point particle. If this assumption did not hold, and the she actually rotated, the force due to the scale on the shoe is not perfectly horizontal. The shoe will begin sliding only when the horizontal force , which is a component of of the scale reading is equal to F_f^{max}. If we use the scale reading as F_f^{max}, our value of μ will be greater.

Experimental uncertainties:
According to the weakest link rule, the uncertainty in the mass measuring scale is $\pm 0.5g$ and that in the spring scale is $\pm 0.05N$. There is also an uncertainty in deciding the point at which the scale reading must be noted. The spring scale uncertainty is much larger. To minimize the uncertainty we repeated the experiment four times.

$$m = 320g \pm 0.5g = 0.32kg \pm 0.0005kg$$

$$\begin{aligned} Trial1 : F_{scale-shoe} &= 1.7N \\ Trial2 : F_{scale-shoe} &= 1.6N \\ Trial3 : F_{scale-shoe} &= 1.7N \\ Trial4 : F_{scale-shoe} &= 1.8N \end{aligned}$$

Average $F_{scale-shoe} = 1.7 \pm 0.05N = 3\%$. So the error in μ will be $\pm 3\%$.

$$\mu = 1.7N/((0.32kg)(9.8m/s^2)) = 0.558 \pm 0.016$$

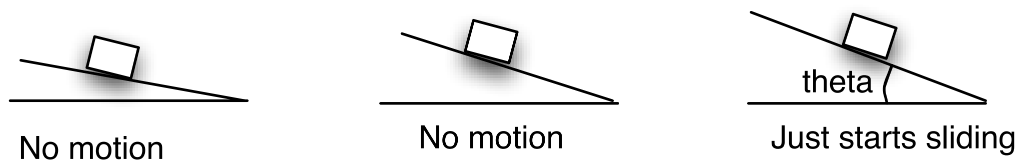
Method 2

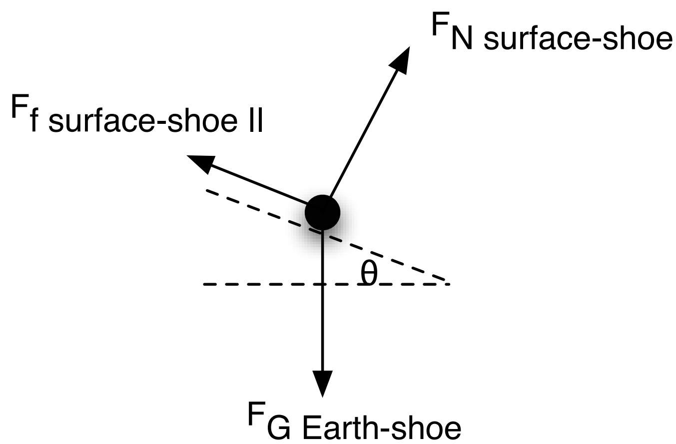
Place the shoe on the carpet and start tilting the carpet. The shoe starts to slide down the carpet at a particular angle. We use the angle at which the shoe just starts sliding to determine μ. We show a schematic picture of the experiemental set-up and a free body diagram for the shoe.

Assumptions:
The shoe slides straight down and does not rotate. Also we assume that as the shoe slides down, the carpet does not get press. If it did then μ will not be uniform over its surface. We cannot determine apriori if our value of μ will be greater or smaller if this assumption were not valid.

$$\begin{aligned} F_N &= mg\ \cos\theta \\ F_f^{max} &= \mu F_N = mg\ \ sin\theta \\ \mu &= tan\theta \end{aligned}$$

We measure the angle between the horizontal table and the tilted carpet using the protractor. The main experimental uncertainty is from the protractor reading. The protractor





has a least count of 1°, so our uncertainty in angle is ±0.05°. We determined the angle at which the shoe just starts sliding four times.

$$\begin{aligned} Trial1: \quad \theta &= 24^\circ \\ Trial2: \quad \theta &= 27^\circ \\ Trial3: \quad \theta &= 26^\circ \\ Trial4: \quad \theta &= 27^\circ \end{aligned}$$

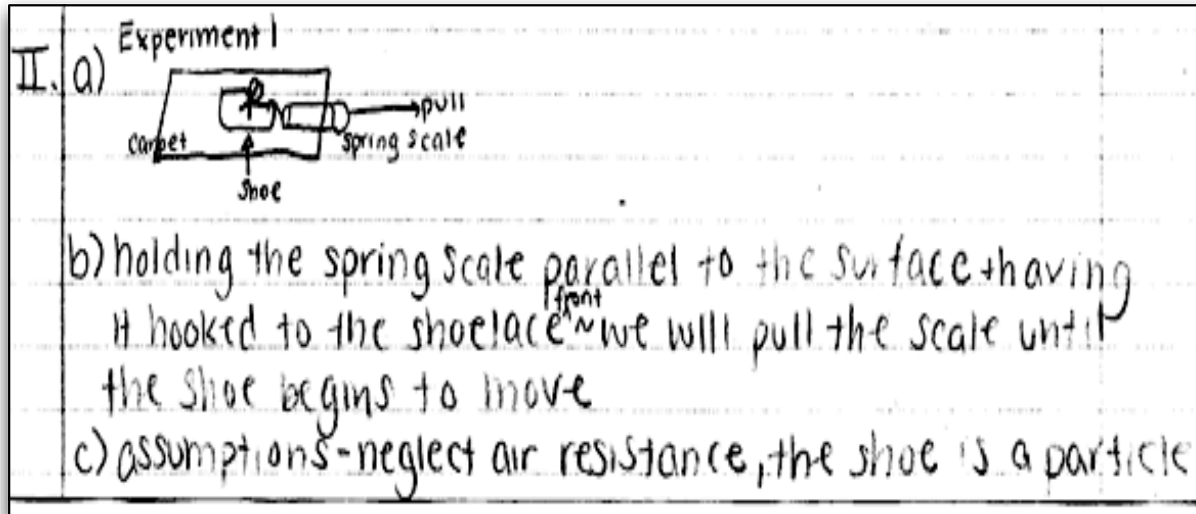
Average angle at which the carpet slides is $26^\circ \pm 0.05^\circ$. $\mu = tan(26^\circ) = 0.48 \pm 0.011$

The first method gives $\mu = 0.558 \pm 0.016$ and the second method gives $\mu = 0.48 \pm 0.011$. The percentage difference is 13%. One reason for the difference could be that the carpet was not a smooth and uniform surface. As the shoe moved, the carpet got "squashed" in certain places. This could have changed μ.

Shortcomings of the experiment:

The procedure assumed that the two surfaces are uniform. It would help if we attached the carpet to a hard surface such as a piece of wood.

Sample student work:

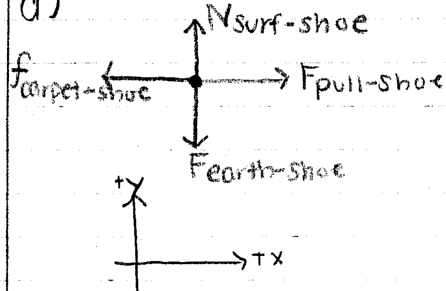


b) holding the spring scale parallel to the surface + having it hooked to the front shoelace ~ we will pull the scale until the shoe begins to move

c) assumptions - neglect air resistance, the shoe is a particle;

these assumptions could affect the results ~ we might find friction to be more than it is b/c we are neglecting air resistance

d)



$f_s = \mu N_{surf\text{-}shoe}$

$N_{surf\text{-}shoe} - F_{earth\text{-}shoe} = ma_y \quad a_y = 0$

$N_{surf\text{-}shoe} = F_{earth\text{-}shoe} = m_{shoe}\, g$

$f_s = \mu m_{shoe}\, g$

e) ~~when we pull forward, the back of the shoe goes up affecting how much friction is acting on the shoe~~; the exact reading of the scale
- these affect our results - ~~we would find friction to be less than it should be~~; affect precise calculations
- ~~add weight to back end of shoe-include in calculations~~; have different people read the results

f) $f_s = 3.3\text{N}$

$m_{shoe} = .367\text{kg}$

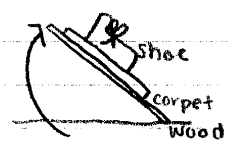
$g = 10\,\text{N/kg}$

$3.3\text{N} = \mu(.367\text{kg})(10\,\text{N/kg})$

$\mu = .899$

Experiment 2

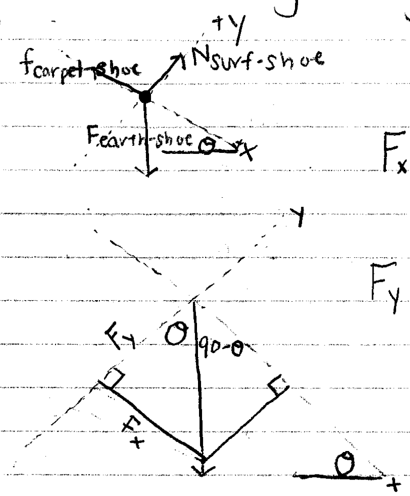
a)



b) we will continue to lift the board vertically until right before the shoe moves

c) the carpet + wood are one system, neglect air resistance; these assumptions could affect our results ~ we might find friction to be more than it is b/c we are neglecting air resistance

d)



$f_s = \mu N_{surf-shoe}$

$F_x = -f_{carpet\ shoe} + F_{earth-shoe} \sin\theta = ma_x = 0$

$f_{carpet-shoe} = m_{shoe} g \sin\theta$

$F_y = N_{surf-shoe} - F_{earth-shoe} \cos\theta = ma_y = 0$

$N_{surf-shoe} = m_{shoe} g \cos\theta$

$f_s = f_{carpet-shoe}$

$*m_{shoe} g \sin\theta = \mu m_{shoe} g \cos\theta$

$\sin\theta = \mu \cos\theta$

e) human error - finding the exact error at the exact moment before the shoe moves ~ would alter our values + calculations; could minimize uncertainties through repitition

f) $\theta = 45°$

$\sin 45° = \mu \cos 45°$

$\mu = 1.00$

g) possible reasons for dif - our areas of experimental uncertainty

h) use a computerized spring scale to determine f_s more precisely; use a fixed protractor to determine the angle more precisely ?

i) to prove Newton's third law + show the impact of experimental uncertainties

① make sure there is enough traction in your sneakers ~ it is important for a good start in a track meet

Scores using rubrics:

Scientific Ability	0	1	2	3
Is able to design a reliable experiment that solves the problem . (Score twice, once for each method.)	The experiment does not solve the problem.	The experiment attempts to solve the problem but due to the nature of the design the data will not lead to an accurate solution.	The experiment attempts to solve the problem but due to the nature of the design there is a moderate chance the data will not lead to an accurate solution.	The experiment solves the problem and has a high likelihood of producing data that will lead to a reliable solution.

Method 1, SCORE: 3 **Method 2, SCORE: 3**

Both procedures are appropriate and correct.

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

Method 1, SCORE: 2 **Method 2, SCORE: 2**

In method 1, it is not very clear from the description what is to be measured when the shoe starts moving. In method 2, it is not clear how the angle is exactly measured.

Scientific Ability	0	1	2	3
Is able to make a judgment about the results of the experiment. (Score twice, once for each method.)	No discussion is presented about the results of the experiment	A judgment is made about the results, but it is not reasonable or coherent.	An acceptable judgment is made about the result, but the reasoning is flawed or incomplete.	An acceptable judgment is made about the result, with clear reasoning. The effects of assumptions and experimental uncertainties are considered.

Method 1, SCORE: 0 **Method 2, SCORE: 0**

There is no judgment about whether the values obtained for μ are reasonable.

Scientific Ability	0	1	2	3
Is able to evaluate the results by means of an independent method	No attempt is made to evaluate the consistency of the result using an independent method.	A second independent method is used to evaluate the results. However there is little or no discussion about the differences in the results due to the two methods.	A second independent method is used to evaluate the results. Some discussion about the differences in the results is present, but there is little or no discussion of the possible reasons for the differences.	A second independent method is used to evaluate the results. The discrepancy between the two methods, and possible reasons are discussed. A percentage difference is calculated in quantitative problems.

SCORE: 1 . Even though two independent methods are used to solve the task, there is very little discussion about the discrepancies between the two results.

Scientific Ability	0	1	2	3
Is able to identify the shortcomings in an experimental design and suggest specific 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. No specific suggestions are made for improvements.	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: 2. Some shortcomings are suggested. A main shortcoming, namely, the compression of the surface of the carpet as the shoe moves, is not addressed.

Scientific Ability	0	1	2	3
Is able to choose a productive mathematical procedure for solving the experimental problem (Score twice, once for each method.)	Mathematical procedure is either missing, or the equations written down are irrelevant to the design.	A mathematical procedure is described, but it is incomplete, due to which the final answer cannot be calculated.	Correct and complete mathematical procedure is described but an error is made in the numerical calculations.	Mathematical procedure is fully consistent with the design. All quantities are calculated correctly. Final answer is meaningful.

Method 1, SCORE: 3 **Method 2, SCORE: 3**

Both mathematical procedures are appropriate. The free body diagrams are correct.

Scientific Ability	0	1	2	3
Is able to identify the assumptions made in using the mathematical procedure (Score twice, once for each method.)	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.

Method 1, SCORE: 3 **Method 2, SCORE: 1**

All important assumptions are addressed in method 1. In method 2, two important assumptions, namely that the shoe only slides down the incline without rotating and μ does not change due to the compression of the carpet, are missing.

Scientific Ability	0	1	2	3
Is able to determine specifically the way in which assumptions might affect the results (Score twice, once for each method.)	No attempt is made to determine the effects of assumptions.	An attempt is made to determine the effects of some assumptions, but most are missing, described vaguely, or incorrect.	The effects of most assumptions are determined correctly, though a few contain errors, inconsistencies, or omissions.	The effects of all assumptions are correctly determined.

Method 1, SCORE: 2 **Method 2, SCORE: 2**

The effects of most assumptions are correctly determined. In both methods, the effect of assuming that the shoe is a point particle (with no rotation) is not addressed.

Scientific Ability	0	1	2	3
Is able to identify sources of experimental uncertainty (Score twice, once for each method.)	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.

Method 1, SCORE: 1 **Method 2, SCORE: 2**

In method 1, the main source of uncertainty is the spring scale reading. This arises from both the least count of the scale, and in being able to decide exactly at which point the scale reading must be noted. There is also a small uncertainty in the measurement of the mass of the shoe. The student has identified only some of these uncertainties, and they are described vaguely. In method 2, the experimental uncertainties arise from the measurement of the angle by the protractor, and deciding the point at which the angle should be measured. There is also a small uncertainty in the measurement of the mass of the shoe. The student has identified the main uncertainties, but not all.

Scientific Ability	0	1	2	3
Is able to evaluate specifically how experimental uncertainties may affect the data (Score twice, once for each method.)	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.

Method 1, SCORE: 1 **Method 2, SCORE: 1**

The student has attempted to evaluate how uncertainties affect data, but they are described vaguely. There is no attempt at using the weakest link rule to estimate these uncertainties.

Scientific Ability	0	1	2	3
Is able to minimize experimental uncertainties. (Score twice, once for each method.)	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.

Method 1, SCORE: 1 **Method 1, SCORE: 1**

The student mentions some efforts at trying to minimize experimental uncertainties, but there is not much evidence of it in the data.

Scientific Ability	0	1	2	3
Is able to record and represent data in a meaningful way (Score twice, once for each method.)	Data is either absent or incomprehensible.	Some important data is absent or incomprehensible.	All important data is present, but is recorded in a way that requires some effort to comprehend.	All important data is present, organized, and recorded clearly.

Method 1, SCORE: 3 **Method 2, SCORE: 3**

All important data are recorded in an organized manner.

Scientific Ability	0	1	2	3
Is able to analyze data appropriately (Score twice, once for each method.)	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.

Method 1, SCORE: 3 **Method 2, SCORE: 3**

The data analysis is appropriate.

Scientific Ability	0	1	2	3
Is able to communicate the details of an experimental procedure clearly and completely (Score twice, once for each method.)	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