UCI Gifted Students Academy
SUMMER 2005

physics
anatomy of a rocket

Course Pack Contents

Rough Sketch of the Week

TIME PERIOD 0915 – 1215 Monday through Friday except Tuesday (45 min for pictures, approx. 1130 – 1215).

CLASSROOM PREPARATION Chairs in circular arrangement; later adjust if necessary. Post physics and astronomy posters on wall.

GENERAL STRUCTURE

Monday	Distribute course packs Discussion: What this course is about Distribute bottle rocket materials Construct bottle rockets and transits Submit rocket designs with feature lists
Tuesday	Launch bottle rockets Discussion: How do rockets work? Newton's laws and conservation of momentum Discussion: Rocket launch problems? Proposed solutions?
Wednesday	Distribute paper airplane materials Fly paper airplanes Discussion: How do paper airplanes work? Newton, Bernoulli, pressure, and lift; applications to rocket stabilization
Thursday	Discussion: Role of pressure in launching bottle rockets More rocket construction time Submit rocket designs with feature lists
Friday	Final touches on rocket construction Launch bottle rockets Discussion: Results of bottle rocket launch Final words: What next? Careers in science and engineering; emerging projects in aerospace; faster than the speed of light? Students complete instructor evaluations

Bottle Rocket Lab

DESIGN PROCESS You and a partner will design, construct, and fly a bottle rocket. Your primary objective in designing the rocket will be to achieve the highest flight possible with the materials available. Feel free to bring materials from home, but please note that you may not change the propulsion method (i.e., no chemical engines; see Fig. 1.).

FIG. 1. Please refrain from using heavy explosives to power your rocket.

Use the attached sheet to sketch the design you plan to build. Please include a side view and a top view, and label the important parts of your design as well as approximate dimensions. A 3D view of the rocket is optional, but may help you to better visualize your design. An example side view is attached, as are directions for building a simple bottle rocket. You should feel free to use these as a starting point, or to ignore them completely. Do not feel compelled to restrict the creativity of your design.

On the back of your design sheet, please list the features you have included in your design and explain how you think each one will help the rocket fly higher.

ROCKET CONSTRUCTION Once your design and feature list are complete, feel free to begin construction. As noted before, you may use any materials you have access to as long as the propulsion method remains unchanged.

PRE-LAUNCH After construction is complete, please use the scales provided to mass your rocket. Write down the mass in grams (g) and kilograms (kg) on the launch datasheet. Note that 1 kg = 1000 g and 1 g = 0.001 kg, so to convert from kilograms to grams you move the decimal point to the right three places.

Before launching your rocket, please use the labeled bottles to measure out the volume of water you wish to fill your rocket with. Note the volume in milliliters (mL) and liters (L) on the launch datasheet. Note that 1 L = 1000 mL. Please also note the mass of the water; for fresh water this is fairly simple because 1 mL = 1 g (and 1 L = 1 kg). Note that this is unique to fresh water; saltwater, liquid nitrogen, heavy chemical explosives, and pretty much everything else in the world do not have such a nice conversion.

If you have time, you may verify the volume-to-mass conversion by massing the water on the scale; note that you will also need to mass the bottle while it is empty, and subtract the empty bottle mass from the mass of the water and bottle together in order to get the mass of the water.

LAUNCH When launching your rocket, please check the reading on the pump pressure gauge at launch and note the reading on your launch datasheet. This is called the “gauge pressure” and is the amount of pressure in the bottle beyond atmospheric pressure. To get the “absolute pressure” add the atmospheric pressure (about 14.7 pounds per square inch [psi] here on earth) to the gauge pressure.

MEASURING THE HEIGHT AT APOGEE When launching, please use your transit (or have somebody else use their transit) to measure the angle between the horizon and your rocket at “apogee” (the highest point in its flight). Note that angle (we can call it the Greek letter “alpha”, written α) on your launch datasheet. Also note the distance on the ground between the person observing the rocket through the transit (we will call this person the "observer") and the launch pad, and write this down. We will call this distance *d*. We will use α and *d* to calculate the rocket's height at apogee, which, logically enough, we will call *h*.

The neat trick that allows us to find *h* with such little information is based on a property of right triangles (triangles with a 90° angle in them). This property says that the *tangent* of any angle is the length of the side opposite that angle divided by the length of the side next to the angle. The tangent (usually abbreviated "tan") is just what is called a "function", which means that we can put some number into it and get a different number out. We can express all of this much more easily with a picture:

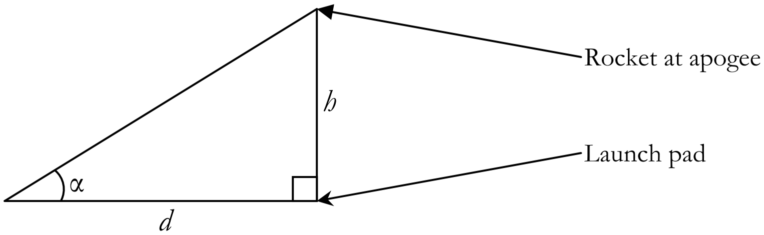

FIG. 2. The right triangle created by the rocket, the launch pad, and the observer.

and an equation:

$$\tan\alpha = \frac{h}{d}$$

We can multiply both sides of this equation by *d* to get an expression for *h*, namely:

$$h = d\tan\alpha$$

Since we already know α and *d*, all we need to do before we can find *h* is find tan α. Luckily, we have calculators that can do this for us. Please use a calculator or a computer to find tan α for the value of α that you measured with the transit, and write it down on your launch datasheet. Then multiply that number by *d*. The product is *h*—that is, it is how high your rocket flew. This is pretty much the most important number of all for each launch, so write it down on your datasheet as well.

POST-LAUNCH After your launch is over, spend some time calculating *h* based on the instructions above. Then discuss the other questions on your launch datasheet with your partner; they are designed to help you think about your launch in such a way that your next launch can be better. Use them to your advantage, so think carefully and do the best you can to answer them thoroughly.

Launch Datasheet

Launch #: _____ Rocket Name: ____________________
Team Name: ____________________ Team Members: ____

Rocket Mass		Water Volume		Water Mass		Pressure (psi)		α (deg)	tan α	b (m)	h (m)
g	kg	L	mL	g	kg	gauge	abs				

Please use words to describe the flight. Describe the launch itself, the path and behavior of the rocket, and anything else you think is important. Feel free to draw a diagram if you think it would be useful.

How was the flight different from what you expected? How was it the same?

Did you test any specific new features on this flight? If so, which features? How did they affect the flight? How does this compare with what you expected to happen?

What did you learn from this flight?

In what ways was this flight a success?

What do you plan to do differently next time?

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Example Bottle Rocket Side View

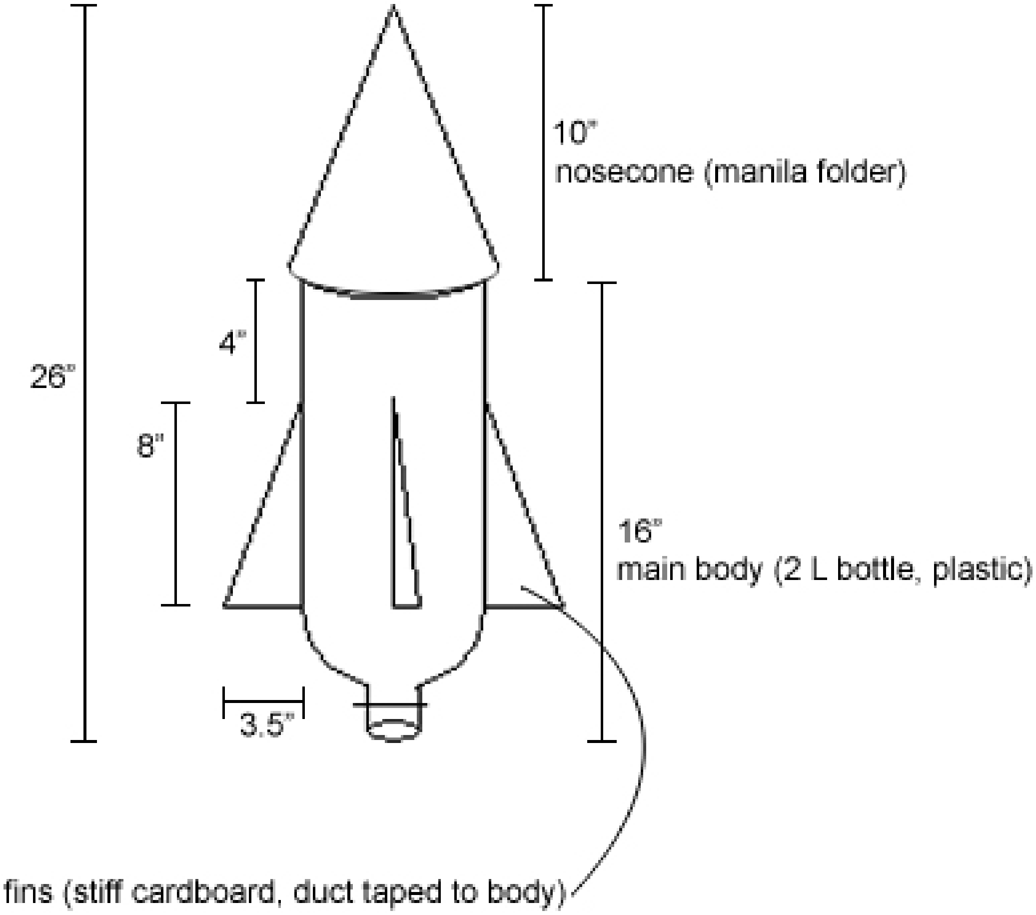
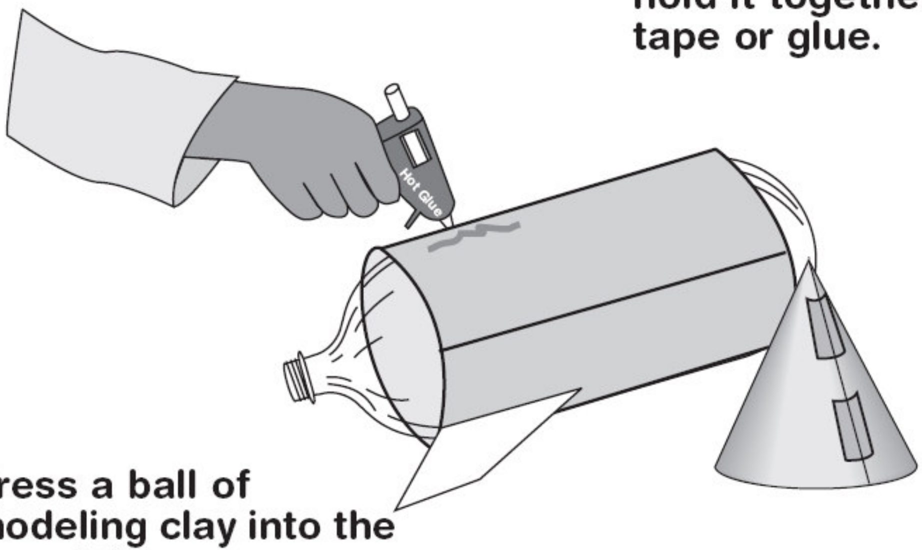


FIG. 3. An example side view for a bottle rocket design.

NOTE You may use whatever units you want for the dimension: inches, centimeters, millimeters...as long as they are clearly labeled and convey the information without confusion.

Construction Guide for a Simple Rocket

1. Wrap and glue or tape a tube of posterboard around the bottle.
2. Cut out several fins of any shape and glue them to the tube.
3. Form a nosecone and hold it together with tape or glue.



4. Press a ball of modeling clay into the top of the nosecone.
5. Glue or tape nosecone to upper end of bottle.
6. Decorate your rocket.

Transit Construction Guide

1. Use a string to tie a weight of any type to the hole at the "crosshairs" of the protractor.

2. With strong tape, attach the flat edge of the protractor to a paper towel tube or PVC pipe. You may wish to cut a slit in the tube in order to stabilize the protractor.

3. That's it: you're done. To use the transit, first level the tube so that the weight points at the ground, causing the string to pass over the center mark (usually 90°) on the protractor. This is your "zero" point. Then, in order to determine the angle between the ground and any object, simply point at the object with the transit so you can see it through the tube (you may wish to add a "crosshairs" of some type to your transit depending on the degree of precision you require). The angle between the string and the zero point is the angle between the horizon and the object you are looking at.

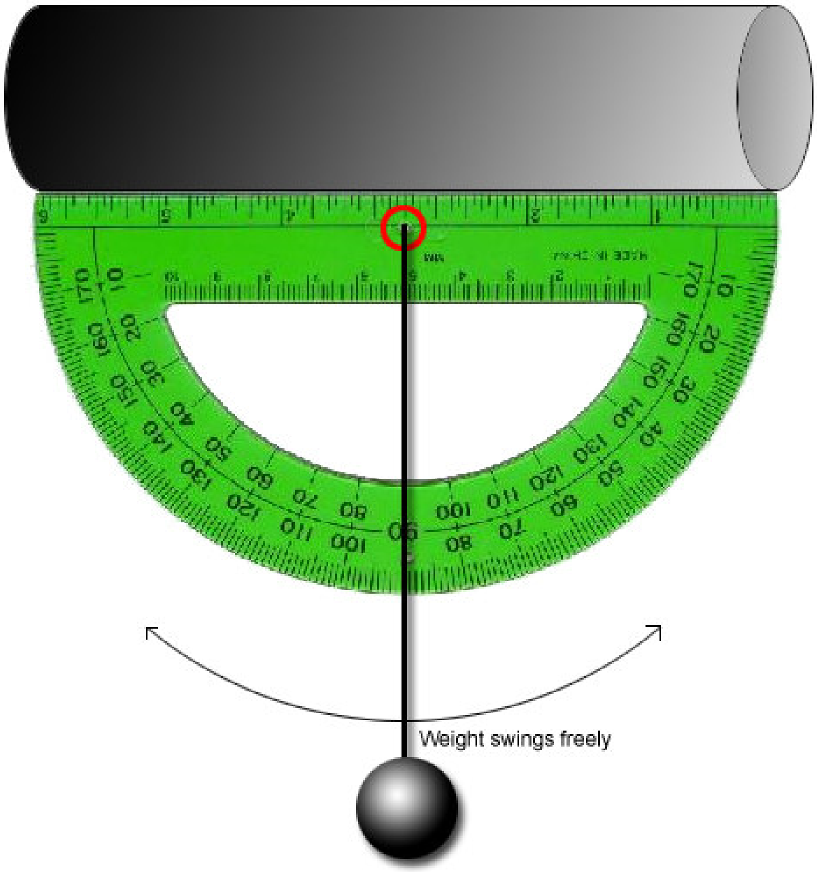


FIG. 4. A completed transit.

Discussion Reference: Newton's Third Law and Conservation of Momentum

NEWTON III The basic operating principle of our bottle rockets is *Newton's Third Law*. Most of you are familiar with this law and have probably heard it stated "For every action, there is an equal and opposite reaction." You can feel Newton III in action pretty much all of the time: right now, you are sitting in your chair—that is, you are exerting a downward force on your chair—and the chair is exerting an exactly equal upward force on you. If it were not—for example, if the chair were to break—then you would fall through the chair.

Newton III and Rockets We saw that when we expelled a lot of water at high speed out the back of our bottles, they became rockets and shot up into the sky. This happened because, essentially, the rocket was exerting a force on the water—and the water was exerting a force right back on the rocket. Because the reaction force is *equal* in magnitude, expelling the water out of the bottle faster will cause the rocket to shoot into the sky faster.

This is more or less the same concept as *conservation of momentum*, which just means that as long as we do not put any energy into the *system* (a system is just a group of objects that we choose), the total motions—or more correctly the total *momentum*—of the objects in the system will not change.

Think about launching our bottle rockets for a moment. Up until the split-second before the launch—even while we are pumping air into the bottle—there is no motion at all: the total momentum in the system is zero. Conservation of momentum tells us that *after* the launch the total momentum must *still* be zero.

We will give momentum the symbol p. Conservation of momentum says

$$p_{before} = p_{after}$$

and in this case we know that $p_{before} = 0$ because nothing is moving before launch. So we know that after the launch

$$p_{bottle} + p_{water} = 0$$

How can this be? Because p_{bottle} and p_{water} have opposite *signs*; that is, one of them is positive—say, p_{bottle}, because the rocket is going up—and the other one is negative. This means that when the water is expelled towards the ground, conservation of momentum says that the rocket *must* fly up into the air.

Paper Airplane Lab

Your objective in this lab is to design a paper airplane that will stay in the air for as long as possible after it is thrown. You may use tape, staples, glue, paper clips, or whatever else you find lying around—but you may only use one piece of 8.5" x 11" paper per airplane (you may, of course, cut or tear it to make it smaller). Before and after each flight, please fill out a flight datasheet and answer the questions. Like in the bottle rocket lab, the questions are designed to help you make a better airplane, so think carefully and answer them to the best of your ability. Although you will be making your own airplanes, you are encouraged to discuss ideas and learn from other peoples' flights.

There are a few instruction sets for different airplane designs at the end of this course pack; feel free to browse through them if you don't yet have a favorite design. Additionally, the instructors will make available several books full of airplane designs. Feel free to get ideas and instructions from them, but please don't tear any paper out of them.

Flight Datasheet

PRE-FLIGHT DATA

Pilot Name: ____________________

Flight #: _____
Design Name (if any): ____________________
Plane Mass: _____ g

Please describe and/or sketch the design.

Please briefly explain why you think the design will fly for a long time. Please mention any unique features or additions to the design that you think will assist in increasing time aloft, and why.

POST-FLIGHT DATA

Time Aloft: _____ s

Briefly describe the flight. Feel free to include a diagram if you think it would be useful.

Discuss how the flight did or did not meet your expectations. What do you think were the most important factors in determining the outcome of the flight? Address plane design factors (including any specific features you may have been testing) as well as external factors like wind (or trees...).

What did you learn from the flight?

What do you plan to do differently next time?

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Discussion Reference: Pressure

DEFINITION Pressure is formally defined as "force per unit area". What this means is that when we say, for example, that atmospheric pressure is 14.7 pounds per square inch (psi), we are saying that the atmosphere exerts 14.7 pounds of force on every square inch of the earth's surface. If the pressure inside a bottle rocket is 100 psi, that means that there is the same amount of force on *every square inch* of the inside surface as there would be if we put a (very compact) 100-pound weight on that square inch. Mathematically, we say that

$$P \equiv \frac{F}{A}$$

where P is the pressure, F is the force, and A is the area over which the force acts. Note that the equals sign with the extra line means "is defined to be".

LAUNCHING ROCKETS WITH PRESSURE When we launch our bottle rockets, we are pumping air into the bottle. But because we block the only exit with water and an airtight seal, we are pumping more and more air into a space that stays the same size. There is an equation (called the ideal gas law) that states this formally, but it is enough to realize that when you pack more stuff into a closed space, things will start to get a little tight. The term we use to describe how tightly the molecules are packed is called the *density*. As we pump more air into the bottle, the density will increase dramatically.

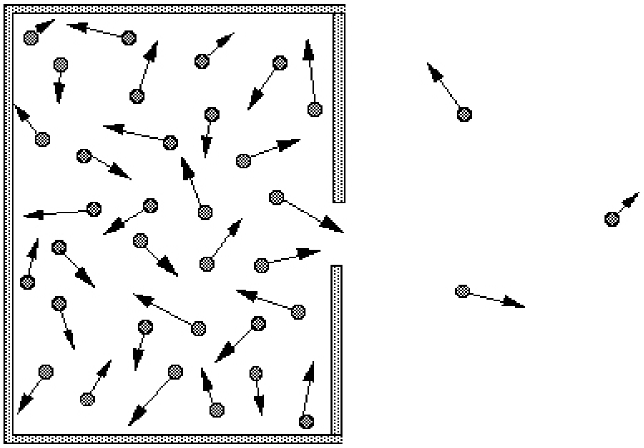

FIG. 5. Left: Air molecules in the bottle, under high pressure. Right: Air molecules in the atmosphere, under lower pressure. Once the seal on the bottle gives out, the molecules in the bottle will rush out so that there is the same density

Of course, what eventually happens—and what we want to happen—is that our airtight seal can no longer hold back the huge amount of air that we have pumped into the bottle. When that happens, the air rushes out of the bottle in an attempt to reach an *equilibrium* with the outside air. Specifically, air will rush out of the bottle until the air density inside the bottle and outside is the same. As the air rushes out, it will push the water—that is sitting between it and the outside air—out of the bottle as well.

It is in fact possible to launch a bottle rocket with just air in it, but if you try it you will notice that the rocket will not fly very far. This is because air has much less mass than water, and so when we expel only water out the back of the bottle, conservation of momentum only imparts a small velocity to the rocket.

Course Evaluation

Please complete this course evaluation thoroughly and honestly; this course exists for you, the students, and your feedback is the most important way for us as instructors to improve our courses and our teaching. We thank you for your honest input.

Session _____
Student Name (optional) ____________________

Please indicate agreement or disagreement with statements 1 through 8 by selecting a number from 1 to 10, where 10 means "I strongly agree" and 1 means "I strongly disagree".

1. I had fun in this course. _____
2. I learned a lot in this course. _____
3. The hands-on activities contributed significantly to my learning. _____
4. The discussions contributed significantly to my learning. _____
5. The handouts contributed significantly to my learning. _____
6. The hands-on activities were relevant and interesting. _____
7. The discussions were relevant and interesting. _____
8. The handouts were relevant and interesting. _____
9. Having more than one instructor improved the course experience. _____

Please answer the following questions.

10. What do you think were the best parts of the course?

11. What would you change about the course or do differently if you were an instructor?

12. Do you feel that the course helped you gain an understanding of what physics is and what it means to "do" science? If so, was there any activity or event in particular that you felt stood out? If not, how do you think we could do a better job at conveying those ideas?

13. Would you take a physics course (not necessarily this one) again in the future, if you could?

14. Would you recommend this course to your friends?

Please feel free to make any additional comments or suggestions on the back of this sheet or on a separate piece of paper.

Instructor Evaluation

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Session _____
Student Name (optional) ____________________
Instructor Name ____________________

Please indicate agreement or disagreement with statements 1 through 8 by selecting a number from 1 to 10, where 10 means "I strongly agree" and 1 means "I strongly disagree".

1. The instructor knew the material well. _____
2. The instructor explained the material well. _____
3. The instructor was approachable and helpful rather than intimidating. _____
4. The instructor ensured that all students were involved in the learning process, including hands-on activities and discussions. _____
5. The instructor was a pleasant person to be in the classroom with. _____
6. The instructor was genuinely interested in engaging both the students and the material. _____
7. The instructor contributed significantly to my understanding of the material. _____
8. The instructor contributed significantly to my understanding of what it means to "do" science. _____

Please answer the following questions.

9. What did the instructor do best?

10. What advice would you give the instructor to improve his/her teaching?

11. Would you take another course with this instructor?

12. Would you recommend this instructor to a friend?

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Course Materials List (for One Week)

For this materials list we assume that the class has 20 students.

Bottle Rocket Materials and Equipment
- 10 plastic 2-liter bottles
- 5 manila folders
- About 10 8.5” x 11” sheets’ worth (total of 935 in^2) of stiff cardboard (actual sheet size is unimportant)
- About 1 liter of Play-Doh or similar material
- 2 average-sized rolls of duct tape (1.88” x 45 yd or similar)
- 2 to 4 electronic or triple-beam balances

Transit Materials
- 10 standard protractors with holes at the origin
- 10 cardboard tubes or PVC pipes
- 1 roll of standard string (approx. 50 yd; for transits and students who wish to construct a parachute system)
- 10 small weights, balls, or large marbles (for transits)

Paper Airplane Materials
- 100 sheets standard white or colored paper (no less than 20 pound)
- 4 standard rolls of stationery tape
- A few dozen paper clips of varying sizes

General Use Materials
- Colored pencils and/or markers
- 10 pairs of scissors
- One bottle of Elmer’s or similar glue
- 5 to 10 calculators