Exploration Brief

Micrometeoroids and Space Debris

Context

Astronauts on spacewalks are likely to encounter fast-moving particles called meteoroids. A meteoroid is usually a fragment of an asteroid consisting of rock and/or metal. It can be very large with a mass of several hundred metric tons, or it can be very small—a micrometeoroid which is a particle smaller than a grain of sand. Micrometeoroids are usually fragments from comets. Every day Earth's atmosphere is struck by millions of meteoroids and micrometeoroids. Most never reach the surface because they are vaporized by the intense heat generated by the friction of passing through the atmosphere. It is rare for a meteoroid to be large enough to survive the descent through the atmosphere and reach solid Earth. If it does, it is called a meteorite.

In space there is no blanket of atmosphere to protect spacecraft from the full force of meteoroids. It was once believed that meteoroids traveling at velocities up to 80 kilometers per second would prove a great hazard to spacecraft. However, scientific satellites with meteoroid detection devices proved that the hazard was minimal. It was learned that the majority of meteoroids are too small to penetrate the hull of spacecraft. Their impacts primarily cause pitting and "sandblasting" of the covering surface.

Recently spacecraft debris is of great concern to spacecraft engineers. Thousands of space launches have left many fragments of launch vehicles, paint chips, and other "space trash" in orbit. Most particles are small, but they travel at speeds of nearly 8,000 meters per second. These space-age particles have become a significant hazard to spacecraft and to astronauts on extravehicular activities.

Engineers have protected spacecraft from micrometeoroids and space trash in a number of ways, including thick-wall construction and multi-layer shields consisting of foil and hydrocarbon materials. A micrometeoroid striking multi-layer shields disintegrates into harmless gas that disperses on inner walls. Spacesuits provide impact protection through various fabric-layer combinations and strategically placed rigid materials.

Although effective for particles of small mass, these protective strategies do little if the particle is large. It is especially important for spacewalking astronauts to be careful when they repair satellites or do assembly jobs on the International Space Station. A lost bolt or nut could damage a future space mission through an accidental collision. (Note: Low orbit tends to be clearer of particles than higher orbits because low orbit particles tend to decay and burn up in the atmosphere.)

Investigation

Pea Shooter Meteoroids

The effects of high-speed micrometeoroid impacts can also be simulated with a "pea shooter." The shooter is actually a plastic milkshake straw. The projectile can be dried peas, popcorn, dried lentils, etc. The object of the activity is to penetrate tissue paper with the projectile. As with the Potato Astronaut activity, the velocity of the impactor determines the penetration.

Materials and Tools Checklist

- ☐ Plastic milkshake straw
- ☐ Dried peas, popcorn, etc.
- ☐ Tissue paper (for wrapping presents)
- ☐ Cardboard box
- ☐ Tape
- ☐ Eye Protection

Objective

• To compare the effect on tissue paper penetration between low and high speed projectiles.

Procedure

Step 1. *Cover the opening of a box with tissue paper. Stretch the paper tight.*

Step 2. *Drop a pea or other projectile from a distance of approximately 1 meter on to the tissue paper. Does the pea penetrate?*

Step 3. *While wearing eye protection, stand back a few meters from the box and blow the pea through the pea shooter at the tissue paper. Does the pea penetrate? (With a little practice, the pea should penetrate the paper.)*

Step 4. *Investigate what happens when more than one layer of tissue paper is used to cover the box opening.*

Safety Precautions

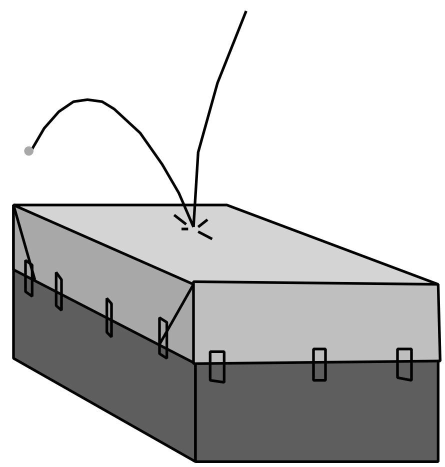
Students must wear eye protection. Caution students not to inhale through the straw.

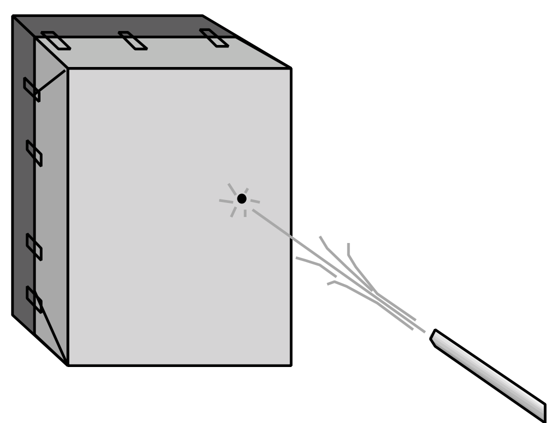
Connections: Mathematics

Refer to the "Potato Astronaut–Part One" activity that follows.

Extensions

- Tape two straws end to end. Does that increase the velocity of the projectile?
- Experiment with projectiles that have a greater mass than the pea.
- Add a second layer of tissue paper to the box to see what effect the second layer has on penetration.
- Is there any relationship between the ability to penetrate the tissue paper and the distance the shooter stands from the box?





Investigation

Potato Astronaut—Part One

The effects of high-speed micrometeoroid impacts are simulated with a potato and a straw. Students hold the potato in one hand and stab it with the other using a plastic milkshake straw. The penetration depth into the potato relates to the speed of the stabbing action. A straw slowly pushed into the potato collapses. The plastic isn't strong enough to support the force exerted at the opposite ends of the straw. However, when the straw is thrust rapidly into the potato, the straw easily penetrates and passes through. The straw enters the potato before it has a chance to collapse. As it enters, the surrounding potato helps support the straw by shoring up its sides.

Materials and Tools Checklist

- ☐ Potato
- ☐ Plastic (milkshake-size) straw

Objective

• To investigate the relationship between velocity and penetration depth when a potato is struck with a plastic straw.

Procedure

Step 1. *Hold a raw potato in one hand. (See illustration.) While grasping the straw with the other hand, stab the potato with a slow motion. Observe how deeply the straw penetrates the potato.*

Step 2. *Repeat the experiment but this time stab the potato with a fast motion. Observe how deeply the straw penetrates the potato. Compare your observations with the results of step 1.*

Safety Precautions

Be careful to hold the potato as illustrated so that the straw does not hit your hand. Work gloves will provide additional protection.

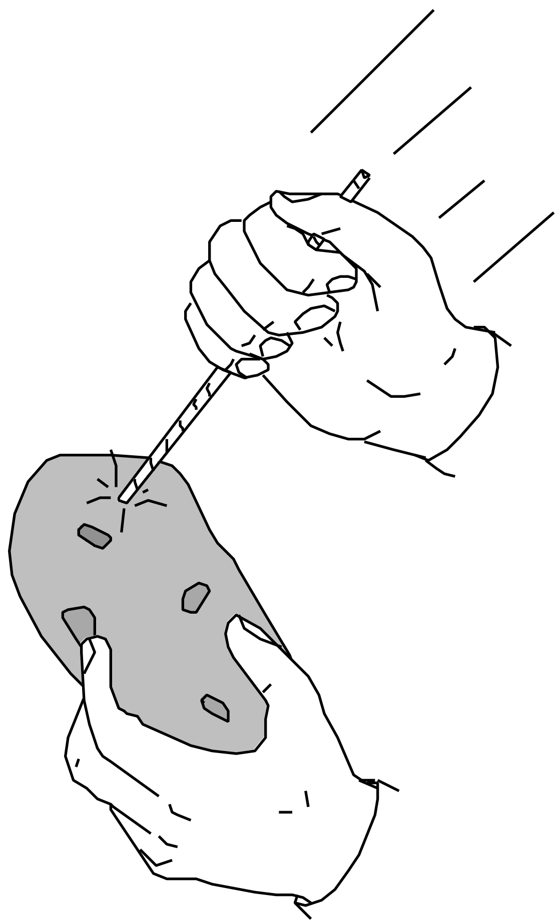
Connections:Mathematics

The kinetic energy output of an impact, given in Joules, is calculated with the following equation:

$$KE = 1/2mv^2$$

m = mass of impacting object
v = velocity of impacting object

Note: The mass in this activity is actually the combined mass of the straw and the hand and forearm driving it.



Investigation

Potato Astronaut—Part Two

In part one of Potato Astronaut, students found that "high speed" impacts enabled the plastic straw to penetrate the potato without collapsing. Challenge the students to design a way to protect the potato from damage caused by impacts using just the materials they brought to the classroom. Their solutions to the challenge should be flexible and light in weight.

Materials and Tools Checklist

- ☐ Plastic (milkshake-size) straw
- ☐ Potato
- ☐ Tissue paper, notebook paper, handkerchiefs, rubber bands napkins, aluminum foil, wax paper, plastic wrap, etc.
- ☐ Impact Resistance Test Stand (from Teacher Tech Brief)

Procedure

Step 1. *Students design a method for protecting potato astronauts from damage caused by the plastic straw when the straw is quickly stabbed into the potato.*

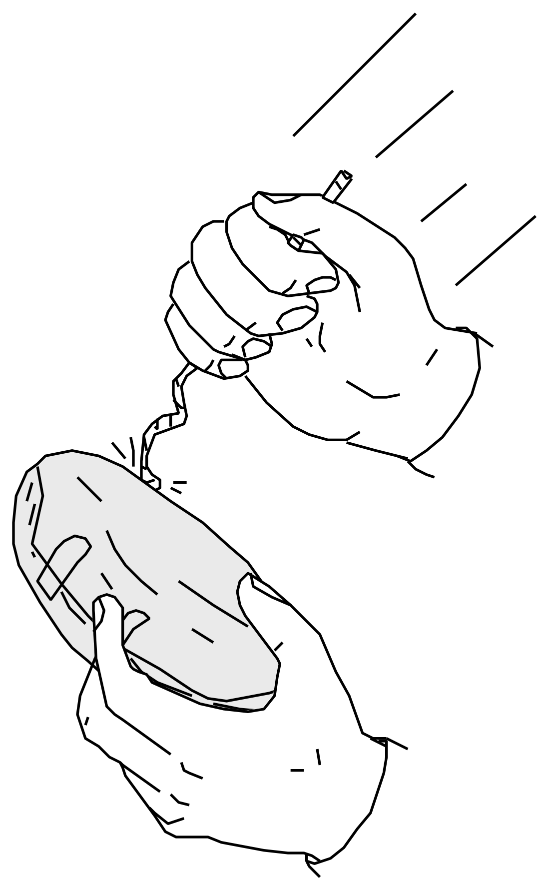
Step 2. *After students have tested a method for protecting a potato, conduct a discussion to evaluate technologies developed. Refine the constraints for a protection system (e.g. the materials used must together be no thicker than __ mm).*

Step 3. *Have students redesign their system based on the refined constraints. Conduct additional impact tests with the straw.*

Step 4. *Test protection systems by using the an Impact Resistance Test Stand as described in the Teacher Tech Brief found earlier in the guide. Evaluate the effectiveness ofthe protection systems developed.*

Extensions

- Compare technologies for protecting astronauts from micrometeoroid and space debris impacts to other protective technologies such as bullet-proof vests, suits of armor, shields on power tools, and windshields on vehicles. How does the function determine the form? (e.g. Motorcycle helmet–provide protection during crash . . . be streamlined . . . comfortable to wear . . . protect face from bug and rock impacts, etc.)
- Experiment with different fabrics and fabric combinations for protective garments.



Teacher Tech Brief

Impact Resistance Tester

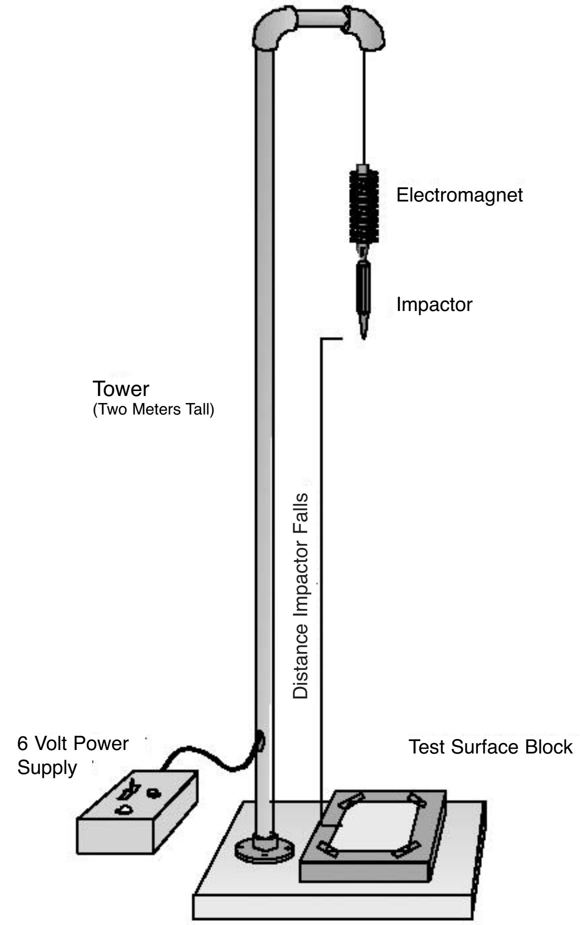
Graphic
One of the hazards of spacewalking is the presence of small high-speed particles. These particles are called micrometeoroids and usually are smaller than a grain of sand, have a mass that is only a fraction of a gram, and travel at speeds ranging from a few to as many as 80 kilometers per second. An astronaut struck by a micrometeoroid could be severely injured. Furthermore, the near-Earth space environment has the additional problem of space debris such as paint chips and metal fragments from old rocket boosters and satellites. Being struck by one of these particles is equally dangerous. As a consequence, spacesuits have to be constructed from materials that are resistant to impacts.

Purpose
This test stand measures the resistance of sample materials to impacts.

Principle
The test stand consists of a tower, made from pipe, with an electromagnet near the top. A center punch (impactor) is suspended from the magnet and drops when the electricity is cut off. The center punch falls into a test sample placed below.

Materials and Tools Checklist
- ☐ Wooden base (6" x 1" x 2')
- ☐ PVC plastic water pipe (3/4" x 10')
- ☐ Pipe elbows (2 pcs)
- ☐ Pipe flanges (1 pc)
- ☐ Screws for flange
- ☐ Bell wire
- ☐ Large eye screw
- ☐ Electronic project box
- ☐ On/off switch
- ☐ Pilot light
- ☐ Push button switch
- ☐ 6 volt battery holder
- ☐ Wooden block (1" x 6" x 6")
- ☐ Center punch
- ☐ Screw driver
- ☐ Meter stick
- ☐ Test materials
- ☐ Tape or pins

Operation
Cut the material to be tested into a small square and tape or pin it on the test surface block (1" x 6" x 6" wooden block). After positioning the test material, turn on the electromagnet and attach the impactor.



Measure the distance between the point of the electromagnet and the test material. When the impactor and magnet stop swinging, turn off the electric current to release the impactor. As it falls, the impactor will accelerate into the sample and make a dent or even penetrate it. Evaluate the resistance to impacts of various materials by comparing the damage done to them. Use a metric ruler for measuring the diameter of the dent or hole.

Mathematics Equations

In physics, the energy of a moving object is called kinetic energy. The amount of that energy is related to the object's mass and its speed. The equation below can be used to determine the kinetic energy of the falling center punch at the moment of its impact on the test surface. The answer will be in joules (unit of work equal to a force of one Newton exerted over a distance of one meter; in English units, a joule is approximately equal to 0.75 foot pounds).

$$KE = 1/2\ mv^2$$

m = mass of impactor
v = velocity at impact

To determine the velocity at the impact, use the following equation:

$$v = gt$$

g = the acceleration of gravity or $9.8 m/second^2$
t = length of time the impactor fell

To determine the length of time the impactor falls. use the following equation:

$$t = \frac{\sqrt{2d}}{g}$$

d = the distance the impactor fell, in meters

Sample Problem
d = 2 m
Impactor mass = 50 grams
What is KE?

$v = 9.8 m/s^2$
x 0.64s = 6.3m/s
KE = 1/2 x 0.05kg x (6.3m/s) 2 = 1.19 joules

Special Note

In this simulation of micrometeoroid impact we are substituting an impactor with a large mass and low velocity for a micrometeoroid with a small mass and a high velocity. The reason for this can be seen in the first two equations on the previous page. Velocity is a quadratic factor while mass is a linear factor. Because of this trade, we can achieve similar damage to the surface of a material being impacted. However, micrometeoroids usually vaporize upon impact. If the surface layer is penetrated, the gas produced disperses on the material beneath.

Safety Precautions

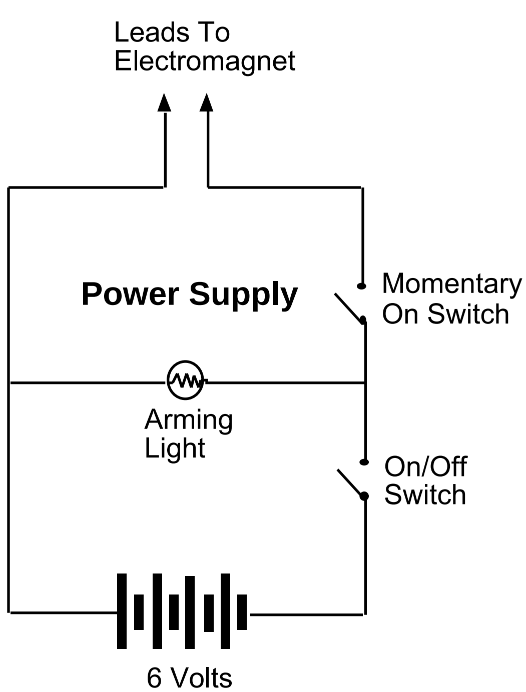
1. **All operators and observers must wear eye protection during drops.**

2. **The materials to be tested should be placed on the test stand before the impactor is suspended from the electromagnet. Nothing but the material to be tested should under the suspended impactor.**

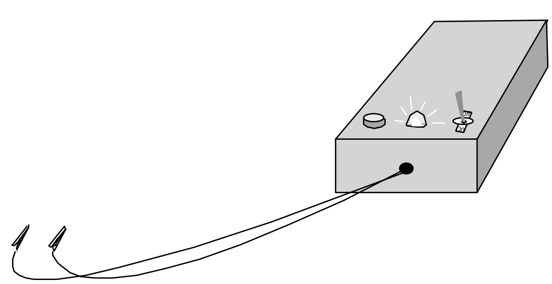
Tips

- Parts for the impactor design pictured in this activity are available from hardware stores (pipe parts, screws, eye screw, center punch) and electronic parts stores (project box, switch, battery holder, pilot light, electromagnet wire).
- Make your electromagnet by wrapping electromagnet wire about 400 times around a large eye screw. When the magnet is electrified the blunt end of the impactor will be held by the magnet. When the current is turned off, the magnet impactor will drop straight to the target.
- Have students bring in various materials for testing such as fabrics and plastics. Encourage students to create composite materials by combining two or more materials together.
- Ask students to keep a test log containing data from each test. Encourage students to predict the amount of damage a sample will receive during a test and compare that to the actual results.
- Discuss the relative merits of the materials the students tested. For example, a thick layer of

Wiring Diagram for Power Supply



Finished Power Supply



steel would make an excellent micrometeoroid shield but would probably be too heavy and too inflexible to be of use in a Martian suit.

- Before running tests on impact resistance, use Exploration Brief on Micrometeoroids and Space Debris (p. 67) with the students to introduce the topic of spacesuits and impacts. After your students have selected materials for their spacesuit, challenge them to wrap a potato in their materials and see if the materials prevent penetration in the drop test. Refer to the potato astronaut activity for more information.
- A typical micrometeoroid has a mass of 1x10-5 grams and travels at about eight kilometers per second.Upon impact, approximately three joules of work is expended.
- A drop tower is not necessary for this test. The electromagnet can be suspended from a pulley from the ceiling. The tower, however makes the unit very portable and eliminates any hazards associated with attaching a pulley to a high ceiling.
- For younger students, begin studying the mathematics of the device with observations on the speed of the impactor as it falls. It will be observed that the farther the impactor falls, the faster it falls.

Extensions

- The impactor can be dropped from any height when testing materials. At what height should the impactor be suspended to equal the impact of a micrometeoroid in space if the micrometeoroid has a mass of 1x10-5 grams and a velocity of 8,000 meters per second? Velocity of 16,000 meters per second? (Your answers will depend upon the mass of the impactor you use.)
- How much kinetic energy is expended by the micrometeoroid above?
- Challenge the students to combine the equations on the previous page into simpler mathematical statements.
- How high should the impactor be before dropping to simulate the impact of a micrometeoroid with a mass of 1x10-5 grams and a velocity of eight kilometers per second? How high should the impactor be suspended if the micrometeoroid's velocity is 16 kilometers per second?