OBJECTS OF DIFFERENT MASSES FALL THROUGH A VACUUM AT THE SAME RATE

TOPIC:

Air Resistance and the Acceleration of Falling Bodies

SCIENTIST:

Robert Boyle 1627–1691

INTRODUCTION:

Early in the seventeenth century the great Italian scientist Galileo Galilei (see 1.017) questioned the teachings of Greek philosopher Aristotle (384–322 BC) concerning the rate at which bodies fall to earth. According to Aristotle, if two objects fall to the ground, the heavier one falls faster. Galileo disproved this with a series of experiments, including the legendary dropping of a cannon ball and a smaller musket ball from the top of the leaning tower of Pisa: both balls landed at the same time (see 4.003). If the same experiment, however, is carried out with a musket ball and a feather, for example, Aristotle's theory appears correct—the musket ball hits the earth first. In fact, Galileo's prediction is still true but the effect of gravity on the feather is masked by the resistance of air to its falling. The only way to test this is to repeat the experiment in a vacuum—that is, where there is no air resistance. This is what Robert Boyle did shortly after Galileo's death. Boyle had developed an air pump, which he used to create a vacuum in a glass jar containing a lead musket ball and a feather. When the glass jar was turned upside down, both feather and musket ball reached the bottom of the jar at the same time, showing that Galileo's theory was correct.

TIME NEEDED:

1 hour

MATERIALS:

Plexiglas® tube, 1 to 1.5 m long, internal diameter greater than 2.5 cm
2 stoppers to fit tube, one with a hole through it
thick-walled rubber or plastic vacuum tubing 1.5 to 2 m long, 0.5 cm internal diameter
2 hose clamps to fit around vacuum tubing
screwdriver to tighten hose clamp
copper or glass tubing 10 cm long to fit through hole in stopper
laboratory vacuum pump or Mityvac® hand pump
small coin (*e.g.*, a dime or a penny)
small down feather
ring stand and clamp

Original Materials:

Boyle used a vacuum pump of the type shown in the illustration accompanying his biography (see 1.009). Instead of the coin you will use, Boyle used a musket ball.

Safety Precautions

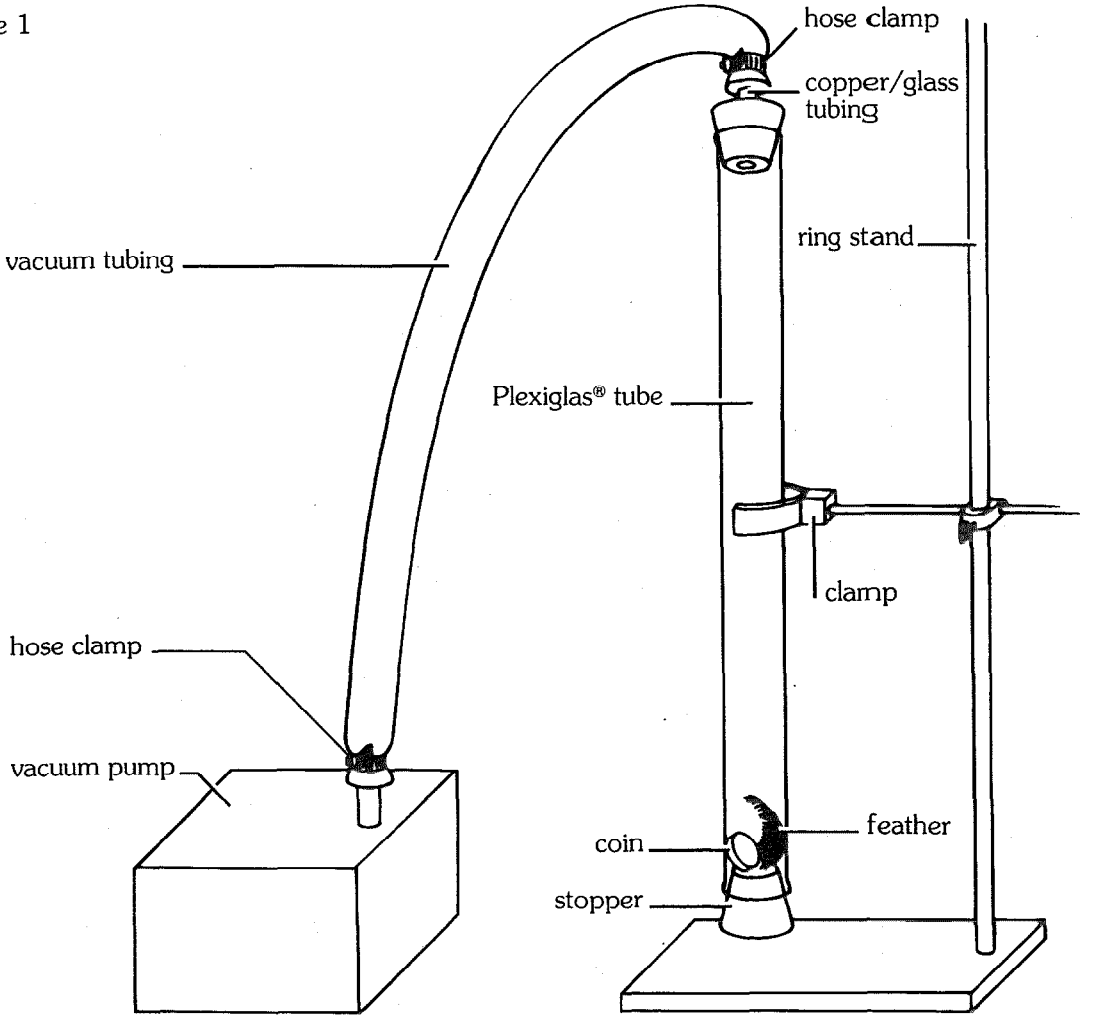
Adult supervision required. Please read and copy the safety precautions at the beginning of this book. Be careful when using the vacuum pump, especially if glass tubing is used to connect the Plexiglas® tube to the vacuum tubing.

PROCEDURE:

Caution: Do not rub the tube during the experiment or the feather might stick to the side because of static electricity generation.

1. Put the solid stopper into one end of the Plexiglas® tube.
2. Ask the adult to push the copper or glass tubing through the other stopper. Be especially careful if pushing glass tubing through the stopper; if necessary, wet the tubing with water before pushing it through.
3. Put the coin and the feather into the Plexiglas® tube. Seal the other end of the tube with the stopper with the copper or glass tubing.
4. Turn the tube upside down so that the coin and feather fall from one end to the other. Note what happens when you do this.
5. Turn the Plexiglas® tube upside down again so that the solid stopper is at the bottom.
6. Ask the adult to fit one end of the vacuum tubing over the copper or glass tubing pushed through the stopper. Put a hose clamp around the end of the vacuum tubing attached to the copper or glass tubing (see figure 1) and tighten it with a screwdriver.
7. Clamp the Plexiglas® tube in the upright position using the ring stand and clamp.
8. Attach the other end of the vacuum tubing to the vacuum pump. Put a hose clamp around the end of the vacuum tubing and tighten it with a screwdriver (see figure 1).

Figure 1



9. Ask the adult to switch on the vacuum pump and pump the air out of the tube. Leave the vacuum pump attached to the tube.
10. Release the Plexiglas® tube from the clamp.

11. Turn the Plexiglas® tube upside down so that the coin and feather fall from one end to the other. Note what happens when you do this. Repeat this step.
12. Ask the adult to let the air back into the tube. Repeat step 11.

ANALYSIS:

1. What happened to the coin and feather when you turned the tube upside down in step 4?
2. What happened to the coin and feather when you turned the tube upside down in step 11?
3. What happened to the coin and feather when you turned the tube upside down in step 12?
4. Explain any differences you observed between steps 4, 11, and 12. Do your findings agree with Galileo's predictions?

OUR FINDINGS:

Click on above link to see what we found.

SPECIAL SAFETY NOTE TO EXPERIMENTERS

Each experiment includes any special safety precautions that are relevant to that particular project. These do not include all of the basic safety precautions that are necessary whenever you are working on a scientific experiment. For this reason, it is absolutely necessary that you read, copy, and remain mindful of the General Safety Precautions that follow this note.

Experimental science can be dangerous, and good laboratory procedure always includes carefully following basic safety rules. Things can happen very quickly while you are performing an experiment. Things can spill, break, even catch fire. There will be no time after the fact to protect yourself. Always prepare for unexpected dangers by following basic safety guidelines the *entire* time you are performing the experiment, whether or not something seems dangerous to you at a given moment.

We have been quite sparing in prescribing safety precautions for the individual experiments. We made this choice for one reason: We want you to take very seriously every safety precaution that is printed in this book. If you see it written here, you can be sure that it is here because it is absolutely critical to your safety.

One further note: The book assumes that you will read the safety precautions that follow, as well as those in the box within each experiment you are preparing to perform, and that you will *remember* them. Except in rare instances, these precautions will not be repeated in the procedure itself. It is up to you to use your good judgment and pay attention when performing potentially dangerous parts of the procedure. Just because the book does not say BE CAREFUL WITH HOT LIQUIDS or DON'T CUT YOURSELF WITH THE KNIFE does not mean that you should be careless when simmering water or stripping an electrical wire. It does mean that when you see a special note to be careful, it is extremely important that you pay attention to it.

If you ever have a question about whether a procedure or material is dangerous, wait to perform it until you find out for sure that it is safe.

GENERAL SAFETY PRECAUTIONS

Accidents caused by carelessness, haste, insufficient knowledge, or taking unnecessary risks can be avoided by practicing safety procedures and being alert while conducting experiments. Be sure to check the experiments in this book for additional safety regulations and adult supervision requirements. If you will be working in a lab, do not work alone.

PREPARING:
—Clear all surfaces before beginning experiments
—Read the instructions before you start
—Know the hazards of the experiments and anticipate dangers

PROTECTING YOURSELF:
—Follow the directions step-by-step; do only one experiment at a time
—Locate exits, fire blanket and extinguisher, master gas and electricity shut-offs, eye wash, and first-aid kit
—Make sure there is adequate ventilation
—Do not horseplay
—Wear an apron and goggles
—Do not wear contact lenses, open shoes, loose clothing, or loose hair
—Keep floor and work space neat, clean, and dry
—Clean up spills immediately
—Never eat, drink, or smoke in laboratory or work space
—Do not eat or drink any substances tested unless expressly permitted to do so by a knowledgeable adult

USING EQUIPMENT WITH CARE:
—Set up apparatus far from the edge of the desk
—Use knives and other sharp or pointed instruments with caution
—Pull plugs, not cords, when removing electrical plugs
—Don't use your mouth to pipette; use a suction bulb
—Clean glassware before and after use
—Check glassware for scratches, cracks, and sharp edges
—Clean up broken glassware immediately
—Do not use reflected sunlight to illuminate your microscope
—Do not touch metal conductors
—Use only low voltage and current materials such as lantern batteries
—Be careful when using stepstools, chairs, and ladders

USING CHEMICALS:
—Never taste or inhale chemicals
—Label all bottles and apparatus containing chemicals
—Read labels carefully
—Avoid chemical contact with skin and eyes (wear goggles, apron, and gloves)
—Do not touch chemical solutions
—Wash hands before and after using solutions
—Wipe up spills thoroughly

HEATING SUBSTANCES:
—Use goggles, apron, and gloves when boiling water
—Keep your face away from test tubes and beakers
—Never leave apparatus unattended
—Use safety tongs and heat-resistant mittens
—Turn off hot plates, bunsen burners, and gas when you are done
—Keep flammable substances away from heat
—Have fire extinguisher on hand

FINISHING UP:
—Thoroughly clean your work area and glassware
—Be careful not to return chemicals or contaminated reagents to the wrong containers
—Don't dispose of materials in the sink unless instructed to do so
—Wash your hands
—Clean up all residue and put in proper containers for disposal
—Dispose of all chemicals according to all local, state, and federal laws

BE SAFETY CONSCIOUS AT ALL TIMES