continuously falling toward Earth at the same time as they are speeding forward almost fast enough to shoot out into space. This continuous falling is called **free fall**. The result of continuous free fall is that the spacecraft and everything in it remain balanced in orbit (**Figure 2**).

Sometimes the expression "weightless" is used to describe the effect of constant free fall. **Weight** is the force of gravity acting on an object. When an Earthbound object feels heavy, it is because your muscles must exert a large upward force to overcome the downward pull of gravity, whether it is yourself or some other object you are moving. Although the force of gravity pulls you down, your awareness of gravity comes mainly from the upward forces you must exert to oppose it. In an orbiting spacecraft, the craft and everything in it are continuously falling at the same rate, so the astronaut does not have to exert an upward force to hold onto anything in the spacecraft. Thus, astronauts feel as if there is no gravity; they feel weightless. However, as there is gravity, "weightless" is a poor expression to use.

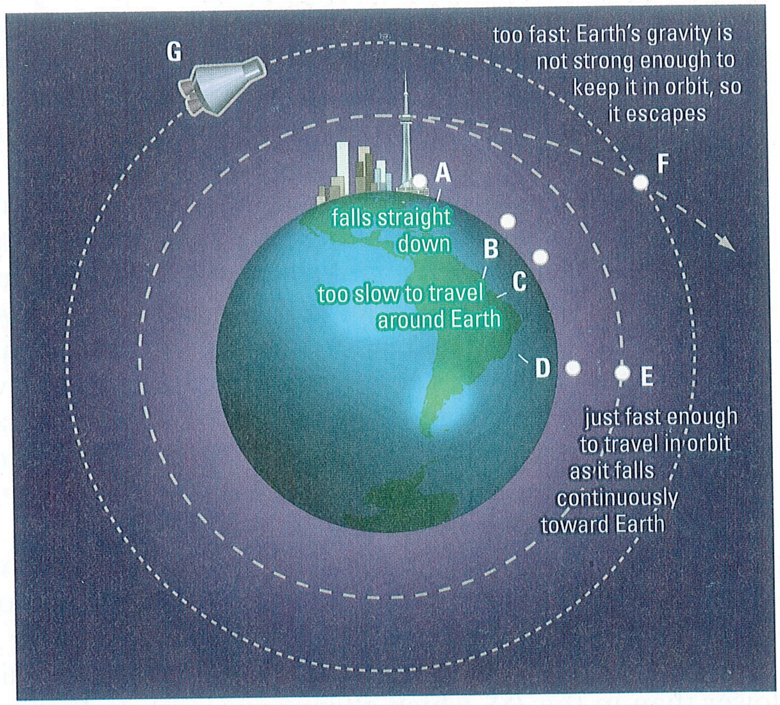


Figure 2

This diagram illustrates constant free fall. Imagine six steel balls that leave a tall tower. Ball A falls straight down while balls B to F get shot outward. Only ball E has the right speed to travel in an orbit around Earth. It follows a curved path just like the spacecraft G, in which astronauts and objects fall together toward Earth as they travel forward at great speed.

Living on the *ISS*

After the shuttle docks with the *ISS*, you enter the station and are greeted by other crew members who have been there for three months. With them, you eat your first space meal, part of which is prepared by adding water to a dry, crumbly mixture in a plastic pouch (**Figure 3**). The other part of the meal consists of fresh vegetables grown on the station as an experiment to help absorb carbon dioxide from the air and provide oxygen for the crew. Water, both hot and cold, is available as a byproduct of the fuel cells that produce some of the energy aboard the station.

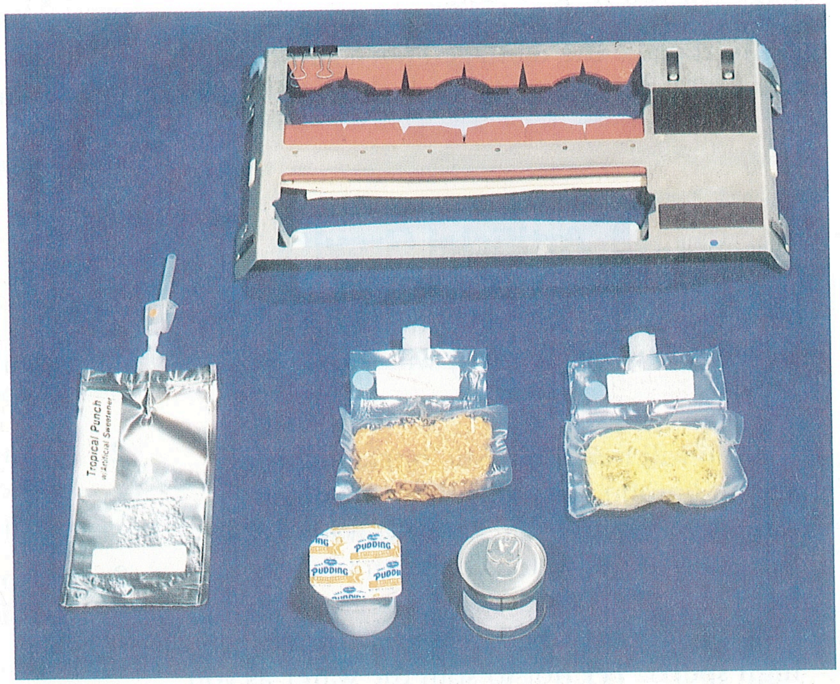


Figure 3

Food in sealed plastic bags is heated in a food warmer.

You do your share of work to help keep the station clean. Sanitation is important in space because microorganisms can grow rapidly in conditions of continuous free fall and an enclosed system like a spacecraft. Allowed to grow unchecked, these microorganisms could cause infections in the astronauts, so the eating equipment, dining area, toilet, and sleeping facilities must be cleaned regularly. Garbage and worn clothing are sealed in airtight bags to be returned to Earth later.

After doing some work at a computer terminal, you talk to your family on Earth and spend a long time exercising on the specially designed treadmills, cycles, and rowing equipment. You must exercise every day to keep your muscles and bones strong and your blood circulating properly. Then, after another meal and relaxation, you fasten yourself into the sleeping hammock tied to one wall.

You spend the next few days working at computers and practising the use of the manipulator arms. You are not allowed to leave the station to carry out your repair tasks until you have been in space at least three days, adapting to continuous free fall.

On the fourth day, you prepare for your first space walk by spending a few hours in a sealed area, breathing pure oxygen, since this is what you will be breathing in your space-walking suit. Breathing pure oxygen means that the air pressure inside your suit can be much lower than in the *ISS*, which allows your joints to be much more manoeuvrable (**Figure 4**) than they would be if your suit pressure was high. Protected by the suit from the vacuum of space and from harmful ultraviolet radiation from the Sun, you go outside the station and attach yourself to the Mobile Remote Servicer Base System (MBS). Using the manipulator system, you grab the satellite that has moved close to the station and pull it close to you. You then replace the satellite's used fuel tank with a fresh one and use the small manipulator arms to replace the damaged part. After testing the satellite, you use the large manipulator arm to push the satellite safely away from the *ISS*.

Did You Know?

You can calculate your own weight by using the equation $F = mg$, where F is the force of gravity, or weight, measured in newtons (N), m is your mass in kilograms (kg), and g is a gravity constant equal to 9.8 N/kg on Earth's surface. On different planets g is different, so your weight would vary! So where would you be truly weightless? Only where you are so far away from all large bodies that the gravity constant, g, is zero. In other words, *way* out in space!

Try This: Artificial Gravity

How can you make "up" into "down"? This model of artificial gravity will show you.

This activity should be done outdoors.

You will need a plastic bucket with a strong handle, a small rubber duck, and water. Half fill the bucket with water. Place the duck in the water. Swing the bucket back and forth until you are ready to swing it in a complete, vertical circle at a fairly high speed. Try not to spill the water as you bring the bucket to a stop.

1. Does the water fall out of the bucket when it is swung quickly in a vertical loop? Explain.
2. From the duck's point of view at the top of the loop, how important is Earth's gravity and which way is down?
3. In what way is this activity a model for "artificial gravity"?
4. How could you apply what you have learned in this activity to a space vehicle that takes humans to and from Mars?

Earth-based controllers then start up the satellite's engines to get it back into its proper orbit.

After three busy months on the *ISS*, you board the shuttle for your trip back to Earth. When the shuttle lands, you may need assistance as you step out and try to walk under the influence of gravity. You feel very heavy at first, but soon you get used to being back on Earth.

Did You Know?

The extravehicular maneuvering unit (EMU) has two aluminum tanks with enough nitrogen to last for six hours of activity. It and the entire spacesuit must be well insulated against temperature extremes, which can range from 120°C down to –150°C.

Figure 4

Space-walking astronauts move around with the help of a backpack called an Extravehicular Maneuvering Unit (EMU). The unit contains compressed nitrogen gas, which can be released through a nozzle. How does the EMU resemble the balloon rocket model or the rocket engine model in Section 16.1, Figures 4 and 5?

Understanding Concepts

1. In your own words, describe why astronauts appear to be floating in the *ISS* or a space shuttle in orbit around Earth, even though gravity is pulling on them.
2. Neither weightlessness nor microgravity are accurate ways to describe the conditions experienced by astronauts. Explain why. What is a more accurate term?
3. Draw a diagram to show how an astronaut who is working outside the *ISS* can use a backpack maneuvering unit (the EMU) to move from left to right.
4. Compare a day of living on *ISS* with a day on Earth. What are the similarities and differences?

Exploring

5. Design an amusement park ride that produces artificial gravity.
6. Research one of the following Canadian astronauts' qualifications, background, interests, and contributions to the space program: Roberta Bondar; Marc Garneau; Chris Hadfield; Steve MacLean; Julie Payette; Robert Thirsk; Bjarni Tryggvason; Dave Williams.
7. Compose an application letter to join the CSA's astronaut-in-training program. Indicate why you want to become an astronaut, what you can add to the space program, and other details.

Challenge

Humans have designed special features and products to survive in spacecraft. What features and products do you need to consider for the space colony challenge?

SKILLS MENU
- ○ Questioning
- ● Hypothesizing
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

Gravity and Free Fall

Have you ever been on an amusement park ride that lets you fall straight downward? If so, you were in free fall. Astronauts on space shuttles or the *International Space Station* experience free fall continuously.

Part 1: Weight and "Weightlessness"

Question

What do the astronauts feel and why?

Hypothesis

1 Write a hypothesis about the relationship between mass and weight of an astronaut in orbit.

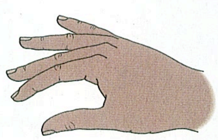
Materials

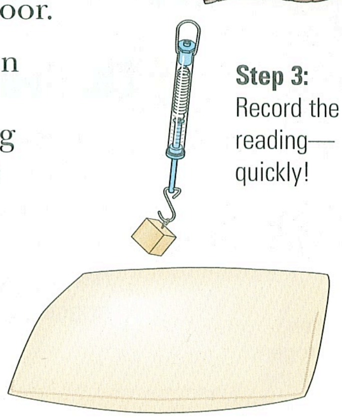
- spring scale that measures weight in newtons (N)
- a hanging mass that registers about halfway on the spring scale
- pillow

Procedure

2 Squat down, then jump up vertically as high off the floor as you can.

(a) Describe what you feel in your leg muscles
  - (i) as your legs are pushing off the floor;
  - (ii) when you are in the air;
  - (iii) as you are landing back on the floor.





Step 3: Record the reading—quickly!

3 Hang the mass on the hook at the base of the spring scale. Determine the apparent weight of the mass (as registered on the spring scale) when
  - (i) the mass is resting on the floor;
  - (ii) the mass is jerked gently upward;
  - (iii) the mass is suspended in midair;
  - (iv) the mass and spring scale are allowed to fall freely toward a pillow on the floor.

(a) Record the four readings you observed.

4 Repeat step 3 twice.

(a) Average your readings for the three trials.

Analysis and Communication

5 Analyze your observations by answering the following questions:

(a) When, in step 2, did
  - (i) your weight feel normal?
  - (ii) you feel heavier than normal?
  - (iii) you feel lighter than normal?

(b) What are the differences between mass and weight?

6 Relate your measurements in steps 3 and 4 to the sensations you felt in step 2.

Part 2: What Affects Free Fall?

Question

What factors affect how fast something falls from a person's raised hand to the floor?

Hypothesis

7 Write a hypothesis to answer the question.

Experimental Design

8 (4B) Design an experiment to test your hypothesis.

(a) Identify the factors you will investigate and describe how you think each will affect the motion of the falling objects.

(b) List the materials you will need.

(c) Write out your procedure. Include any useful diagrams.

SKILLS HANDBOOK: (4B) Designing a Procedure

Procedure

9 After your teacher has approved your procedural steps and materials list, carry out the steps.

(a) Record what you observe.

Analysis and Communication

10 What can you conclude from your observations?

11 A 500-g ball and a 200-g ball are allowed to fall freely from the same height to the floor. Predict how their motions compare.

12 A piece of paper and a marble are allowed to fall toward the floor from the same height. Compare the motions of the two objects if

(i) the paper is flat;

(ii) the paper is crumpled into a ball.

Part 3: Falling While Moving in a Path

Question

What effect does horizontal motion have on the "falling time" of an object?

Hypothesis

13 Write a hypothesis and predict what will happen when you launch one coin horizontally, compared with what will happen when you allow a coin to fall freely downward.

Materials

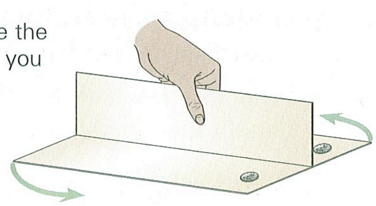
- coin-launching apparatus (shown in **Figure 1**)
- 2 coins

Experimental Design

14 (4B) Design an experiment that uses a coin-launching apparatus to test your hypothesis.

Figure 1

Fold the cardboard and place the coins on it as shown. When you flip the launcher sideways, can you tell which coin will fall straight downward and which will fly sideways? Which coin do you think will land first?



Procedure

15 Make the coin-launching apparatus.

16 After your teacher approves your design, conduct your investigation.

Do not aim the coins at anybody. Launch them only where they will land safely.

(a) Record your observations.

Analysis and Communication

17 Does the sideways motion of a falling object affect its downward falling? Explain.

18 (8A) Write a lab report describing and giving reasons for the different types of motion you observed.

Understanding Concepts

1. As the *ISS* travels in its path around Earth, it is always undergoing free fall. Astronauts inside the station are also experiencing free fall. How does this relate to what you observe about astronauts' motion in the station?
2. Imagine you are in an elevator that is falling freely. You hold out a pen and let it drop. How will its motion compare with yours?
3. Under what circumstances would an astronaut truly be weightless?

Exploring

4. When astronauts train, they experience free fall by going up in a special airplane that falls toward Earth for several seconds at a time. Sometimes the astronauts suffer from motion sickness on this airplane.
   - **(a)** Research information about this airplane and share what you discover with the rest of your class.
   - **(b)** Find out how the actors in the movie *Apollo 13* experienced free fall to make their flight look authentic.

Challenge

What is "artificial gravity" and how might it be applied for long-term space flights? What considerations related to gravity do you have to consider for Challenge 2?

(8A) Reporting Your Work

16.9 Activity

Spinoffs from the Space Industry

How do the hard plastics used for in-line skates, safety helmets, and many other products, relate to space technology? Hard plastics were first designed by the space program to fulfill a specific need, then applied to the products we use (**Figure 1**). This is just one of many examples of a **spinoff**—an extra benefit from technology originally developed for another purpose.

How important will space science be in the 21st century? People who oppose spending on space missions argue that the money would be better spent cleaning up the environment and reducing poverty on Earth. People who promote space exploration argue that the money spent on space missions is only a small portion (under 2%) of any nation's budget. Furthermore, they point out, society benefits from space exploration (**Table 1**).

Procedure

1. Choose a recently developed product, and research how its development began with the space program (see **Table 1** for examples).
2. Design a poster or give an oral presentation tracking your product's research and development, evaluating the product, and giving your opinion on whether to invest in the spinoff.

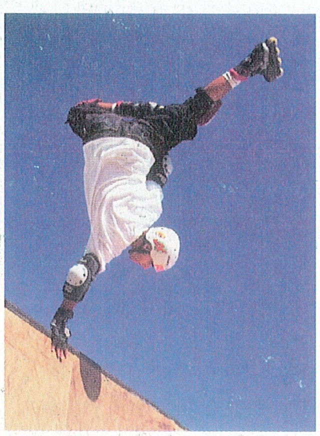


Figure 1

Figure 2

Table 1 Types and Examples of Spinoffs

Area of Research	Examples
microelectronics	digital watches, home computers, pacemakers, hand-held calculators
new materials	nylon strips used to fasten clothing and objects, nonstick coating, flame-resistant materials (**Figure 2**)
metal alloys	dental braces
hard plastics	safety helmets, in-line skates
robotics	mining, industry, and offshore oil exploration where the conditions are too dangerous or the tasks too precise or repetitive for humans
vehicle controllers	controller for those with disabilities
safety devices	smoke detectors
recycling processes	water recycling
energy storage	solar cells, chemical batteries
food	freeze-dried convenience foods
pharmaceutics	antinausea medication to overcome the effects of motion sickness or the side effects of other drugs
pump therapy	method to provide insulin continuously to diabetes patients
scanning	medical scanning using imaging techniques developed for satellites
space vision technology	satellite data applied to improving the efficiency of agricultural spraying
lasers	improved laser surgery

Understanding Concepts

1. What is meant by the term "spinoff"?
2. Which spinoffs listed in this section are most likely linked to Canada's contribution to space science and technology?

Making Connections

3. List some space spinoffs that are now part of your daily life, both at school and at home.
4. What can we learn in space that would benefit the elderly?

Career Profile

Aerospace Engineer

Amyn Samji is not your typical engineer, but he was the one on NASA's graveyard shift monitoring Canada's famous robot, the Canadarm. He had to help remedy the problem of icicle growth on the shuttle.

"It's a long way from Overlea Secondary School to sitting at a console at NASA's Johnson Space Centre," he quietly muses.

Amyn Samji was born in Tanzania, Africa and came to Toronto with his family when he was eight years old. At first he struggled with mathematics, but things changed in high school. "I began to understand relationships and patterns." He joined the mathematics club and a special geometry class.

At the University of Waterloo, Samji took a co-op course in Applied Mathematics and Engineering, followed by a Masters degree in Aerospace Science at the University of Toronto Institute for Aerospace Studies.

Samji's research on robots began when he joined Spar Aerospace, developing computer models for the assembly of *International Space Station* (ISS). Spar engineers were developing the Space Station Remote Manipulator System (SSRMS). Samji developed computer simulations to show how astronauts would exchange parts of the SSRMS.

Later, at NASA's Johnson Space Center, Samji assumed flight support duties, monitoring the Canadarm during missions and solving operation problems. "At 4:00 a.m. on one shift the SSRMS break slip (alarm) went off during a thruster firing. NASA was trying to shake loose an icicle on the orbiter. It was tense. We solved it. It was O.K.," he smiles.

Samji then became the manager of the Mobile Servicing System (MSS) program, Canada's proud contribution to the *International Space Station.*

"Becoming a team player, learning to solve problems, and working hard are important to success in the space business."

Exploring

1. If you were designing a space robot, how would you deal with the harsh conditions it would encounter in outer space?
2. Identify several important characteristics that make a successful project manager.
3. Research post-secondary institutions in your area providing programs that could lead to a career in the space field.

Space Medicine

Human health is an important issue. The study of human health in space—space medicine—is not only fascinating, it is also a great benefit because it helps us learn more about human health on Earth.

Three of Canada's astronauts, Roberta Bondar, Robert Thirsk, and Dave Williams, are medical doctors working in the field of space medicine. Dr. Williams is director of NASA's Space and Life Sciences program.

Space Sickness

An immediate and annoying problem for a human body in orbit is space sickness, a type of motion sickness. During constant free fall, signals from the eyes, skin, joints, muscles, and the balance organs get rearranged. The conflicting clues lead to signs and symptoms of space sickness, such as dizziness, nausea, and vomiting. **Figure 1** explains how the balance organ, located in the inner ear, functions.

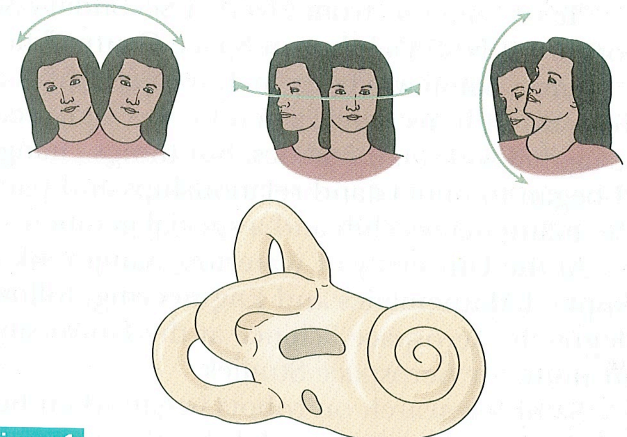


Figure 1

The drawing shows the structure of the inner ear of a human. The three fluid-filled tubes, called the semicircular canals, are responsible for balance. The fluid moves when the head moves: side to side, spinning around, or up and down.

Try This: Your Sense of Balance

Here are two simple activities you can use to test your sense of balance. How does your sense of balance compare with that of other students?

1. Stand on one leg with your eyes open. Then close both eyes and try to maintain your balance.
2. Stand on one leg facing a striped sheet or blanket held by two students. Try to maintain your balance as the blanket is moved sideways, as shown in **Figure 2**.

Have two spotters nearby in case you lose your balance.

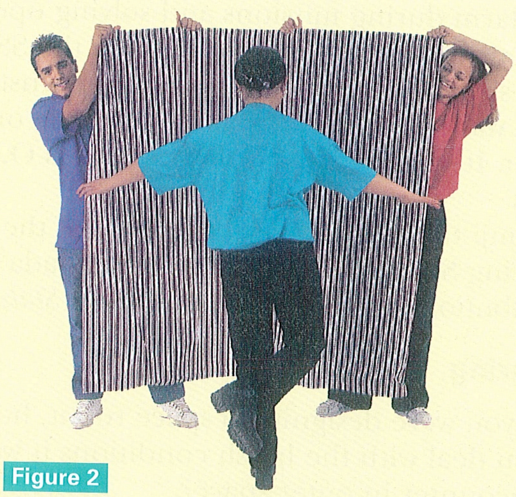


Figure 2

The moving stripes may fool your brain into thinking that you are moving, so your muscles compensate, and you fall over!

Other Effects of Space Flight

Imagine you have had a full-length cast on one leg for three months. The broken bones have healed, and your doctor removes the cast. But your leg still doesn't work normally: although the bones have healed, the muscles have weakened and shrunk from lack of use. It will probably take weeks or even months for you to regain the normal use of your muscles.

Similar problems occur when astronauts are in constant free fall while orbiting Earth. On Earth, your *awareness* of gravity comes mainly from the upward forces needed to oppose it. But in free fall, astronauts are not aware of this gravitational pull. They *feel* weightless, just like the hanging mass that fell with the scale in Investigation 16.8. The lack of forces against the body causes the muscles to become smaller and the bones to lose calcium and become brittle. It seems as though the normal aging process is vastly speeded up. This process can be slowed with a vigorous exercise program during the space flight, but it is not yet known whether this process can be stopped entirely. The data collected during space missions is used in research into the normal aging process. Scientists would like to reduce the deterioration that occurs during both processes.

Another possibly dangerous side effect of space travel involves body fluids. Because of constant free fall, about two extra litres of blood remain in the upper half of the body, swelling the heart and the blood vessels and making the astronauts' faces look puffy and their legs look thinner. More importantly, this condition alters the fluid balance of the body and, in turn, affects the kidneys and causes excess urination. Much is yet to be learned about long-term effects, and research is ongoing.

Astronauts are also exposed to more cosmic radiation on a single trip than they would experience in several years on Earth. We do not yet know whether this exposure is harmful because any effects might not show up for several years. Thus, scientists continue to check the health of space travellers carefully. Space medicine is still a young science, and much remains to be learned about the effects of space travel on the human body.

Did You Know?

When 77-year-old John Glenn went on a space shuttle flight in 1998 to perform experiments on aging, some of the experiments were designed by Canadian scientists. One study related to osteoporosis, a condition of the bones. This was Glenn's second space flight: in 1962 he was the first American to orbit Earth.

Understanding Concepts

1. Describe the effects of constant free fall on the human body. Why do these effects occur?
2. Astronauts must spend a long time exercising each day. Why?

Making Connections

3. How do you think an exercise program in space might be applied to design an exercise program for seniors on Earth?
4. Choose one of the health problems described. How does the research related to it affect the lives of other people not involved in space flight?

Exploring

5. Research the invention of the antigravity suit by Canadian, Dr. W. R. Franks in 1940. Write your own short story about it.
6. Make up an exercise program for astronauts either while aboard the *ISS* or when they return to Earth.

Challenge

Check the NASA web site to obtain more information about NASA's Space and Life Science program. Which contributions have Canadians made to this program?

16.11 Investigation

SKILLS MENU
- Questioning
- Hypothesizing
- Planning
- Conducting
- Recording
- Analyzing
- Communicating

Experimenting in Free-Fall Conditions

Did you know that you are slightly taller when you get up in the morning than when you go to bed? In the daytime, when you are upright, the force of gravity pulls on your spinal column, causing it to crush together. When you are lying down, this crushing is reduced, so the bones spread apart a bit.

This same thing happens to astronauts in constant free fall: they become several centimetres taller. What is more, their bones lose mass, and their muscles weaken because they don't have to work against gravity. Many of their experiments involve finding out what happens to human bodies in space and why. Knowing the answers will help future space exploration as well as the treatment of aging problems on Earth.

In this investigation, you will design an experiment suitable for astronauts to perform on the *ISS* or for the Canadian Space Agency (CSA) to send on a space probe mission.

Question

1 Choose one area of research from **Table 1** that interests you. Plan how you will find out more about that area.

2 Find the information, then choose one topic on which you will base an experiment that will prove useful either to future space flight or to life here on Earth.

(a) Write out the question your experiment will attempt to answer.

Table 1 **Canada's Specialties in Space Science**

Area of Research	Examples of Topics Researched
Space Life Sciences	bone and muscle loss, neurobiology, early development, radiation, heart and circulation system research
Science in Constant Free Fall	crystals, including protein crystals, metals research, fluids research, materials for semi-conductors and fibre optics
Atmospheric Sciences	global warming, Arctic-region research, ozone depletion, middle/upper atmosphere science
Space Astronomy	research using various parts of the electromagnetic spectrum
Solar-Terrestrial Relations	Earth's ionosphere and magnetosphere, the ionosphere on Mars, solar wind, space plasma, aurora research

Hypothesis

3 Write a hypothesis to answer the question.

4 Predict what results you would expect from your experiment.

(a) Write out your prediction, including the controlled and dependent variables.

Experimental Design

5 Design a controlled experiment to answer your question. List the materials needed, the procedural steps, and any safety considerations. Also mention how you would analyze the results.

(a) Write out your experimental design and have it approved by your teacher.

Procedure

6 Conduct your experiment.

Analysis and Communication

7 Create a proposal that would persuade a space agency to conduct your experiment, then submit your proposal.

8 How does performing experiments in space differ from performing experiments on Earth?

Making Connections

1. How do you think your proposed experiment could benefit people or things on Earth?

Exploring

2. Write a short letter, including a relevant question, to a Canadian astronaut on the *ISS*.