Is space-based power possible?

Space-Based Power

Consider the following. The world is becoming increasingly technological, and more technology means more energy use. The question about where to turn next for viable non-polluting energy sources is not a new one. It has long been well known that gases from the tailpipes of automobiles and the smokestacks of coal-fired generating stations produce noxious gases, creating smog such as that shown on the following page. Oil and natural gas reserves will not last forever, and they are not a clean source of energy. The arguments for and against use of nuclear energy have been with us for at least 30 years. What are our alternatives? Windmills? In a few places, yes, but certainly not in most. Is the use of fuel cells a partial answer? How far reaching will be the harnessing of ocean wave power to produce energy? Will fusion power be a viable alternative?

A thick brown haze of smog engulfs a city, the result of incomplete combustion from hydrocarbon fuels.

A radical new idea has been proposed to help meet the ever-increasing need for energy — one that will not negatively affect Earth's environments. The proposal is for the use of space-based power. Could an orbiting satellite capture solar energy before it is diffused by the atmosphere, convert it into microwaves to be beamed to a receiving station on Earth, and from there be transformed into useable electric power? The idea sounds as if it comes from a science-fiction novel. Yet, the concept for such a system is currently under active investigation around the world.

A space-based power delivery system requires the integration of a number of different emerging technologies. Look at just a few of the needs that must be met:

In Space

- Satellites in geosynchronous orbit with photovoltaic panels
- Power-conversion components to convert the electricity from the panels to microwave radiation
- Transmitting antennas to direct microwave beams to Earth

On Earth

- Receiving antennas (called rectennas) to capture the incoming microwaves and convert them into electricity that can be used
- Power-conversion components to convert the direct current (DC) output from the rectennas to alternating current (AC) which is compatible with local electrical grids

Power Reliability

- Power-conversion efficiencies for all weather conditions

Think about these needs as you plan for the Challenge.

Math Link

Only about 5×10^{-8} % of the total energy emitted by the Sun reaches Earth's surface. Try to calculate this value by making appropriate assumptions. The necessary data and equations are provided on the inside front and back covers.

Challenge

Develop and present a case either for or against the use of **space-based power** as a major source of energy to power Earth's technologies in the future. You will use knowledge of concepts investigated throughout this course, and additional research outside this resource, to develop your presentation about the feasibility of space-based power for widespread future use. Your class will together decide whether the presentations will be made:

- through a formal debate
- through role-play
- through research report presentations (either as a written report, an audiovisual presentation, or a poster presentation to an international commission (or to another group you decide upon)
- through another format of your choice

Materials

All presentations must be supported by your portfolio of research findings, the results of supporting experiments conducted, and a complete bibliography of references used. Other materials will be considered under the heading Design Criteria.

PHYSICS FILE

The rough notes of many famous scientists are now treasured artifacts, not only for their scientific value, but also for the window they offer into each scientist's mind and way of thinking. This page shows the jottings of one such thinker, Isaac Newton.

Design Criteria

A. You need to develop a system to collect and organize information that will include data, useful formulas, and even questions that you use to formulate your final recommendation near the end of the course. You can collect your own rough notes in your Physics Research Portfolio (print or electronic).

B. Building a Physics Research Portfolio
Your individual creativity will shape the amount, the type, and the organization of the material that will eventually fill your portfolio. Do not limit yourself to the cues scattered throughout the text; if something seems to fit, include it.

Suggested items for your Physics Research Portfolio:

- experiments you have designed yourself, and their results
- useful formulas
- specific facts
- interesting facts
- disputed facts
- conceptual explanations
- diagrams
- graphical organizers
- useful page numbers
- useful web sites
- experimental data
- unanswered questions

C. As a class, decide on the type(s) of assessment you will use for your portfolio and for its presentation. Working with your teacher and classmates, select which type of presentations you will use (debate, role-play, or research presentation, as outlined previously) to present your space-based power findings.

Action Plan

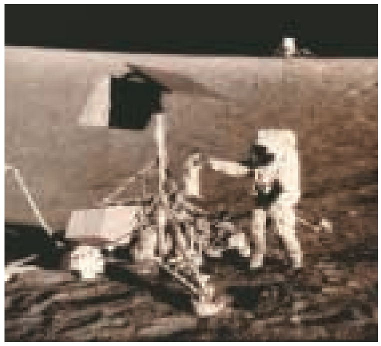
1. As a class, have a brainstorming session to establish what you already know about current and possible future energy sources. For example, what are the different energy sources used around the world today, and what are the pros and cons of each of them? Why is it important to look for alternatives?
2. As a class, design a rubric or rubrics for assessing the task. (You may decide to assess facets of the challenge leading up to the presentation, as well as the presentation itself.)
3. Decide on the groupings, or assessment categories, for this task.
4. Familiarize yourself with what you need to know about the task that you chose. For example, if it's a debate, it is important to research the proper rules for debating in order to carry out the debate effectively.
5. Develop a plan to find, collect, and organize the information that is critical to your presentation and the information you record in your Physics Research Portfolio.
6. Carry out the Course Challenge recommendations that are interspersed throughout the text wherever the Course Challenge logo and heading appear, and keep an accurate record of these in your portfolio.
7. When researching concepts, designing experiments, or following a cued suggestion in the text, the McGraw-Hill Ryerson web site is a good place to begin: *www.mcgrawhill.ca/links/atlphysics*
8. Carry out your plan and make modifications throughout the course as necessary.
9. Present your case to your class. Review each presentation and identify Space-Based Power Supporters and their reasons, as well as Space-Based Power Opposers and their reasons.

Evaluate Your Challenge

1. Using the rubric or rubrics you have prepared, evaluate your work and presentation. How effective were they? Were others able to follow the evidence, results, and conclusions you presented? If not, how would you revise your presentation.
2. Evaluate Course Challenges presented by your classmates.
3. After analyzing the presentations of your classmates, what changes would you make to your own project if you were to have the opportunity to do it again? Provide reasons for your proposed changes.
4. How did the organization of information for this challenge help you to think about what you have learned in this course?

Space Link

The Moon offers a wealth of amorphous silicon. Some supporters of space-based power foresee constructing a photovoltaic manufacturing plant on the moon. Mining the resources of the Moon is an issue of feasibility, but it is also an issue of politics and ownership. In your opinion, what is the likelihood of a Moon-mining plan proceeding if it is contrary to global political will?



Background Information

The following information will give you some idea of the questions you should consider as you try to decide if this proposal is one that you would support or not support in your presentation. A great deal of evidence can come from your studies and investigations throughout this course. Some of the major issues are:

- How will the satellite get into orbit?
- How high should the satellite be?
- How feasible is wireless energy transmission?
- How safely can the beam be focussed?
- How much will it cost?

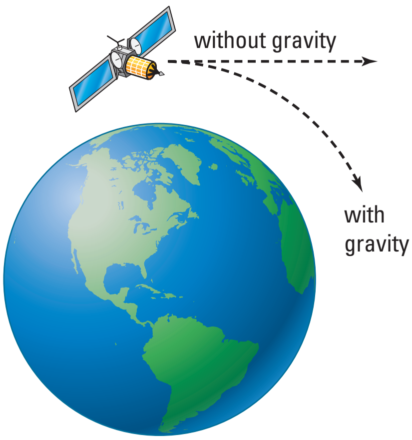
The following sections give you "fuel for thought." They are tied closely to Course Challenge cues in your text so that you may start to develop your plans for this culminating Course Challenge at an early stage in your course.

Getting into Orbit

How fast does an object need to travel to get into orbit around our Earth? Does the amount of speed that a rocket attains determine both the height and shape of the orbit it will trace out? Space-based power schemes need to be able to capture sunlight and then beam the energy as microwaves to a specific spot on Earth.

Staying in Orbit

A satellite, beaming energy in the form of microwaves to Earth, must have an unobstructed "line of sight" to both the sun and the receiving station on Earth.



Astronauts and satellites are not "weightless" when in orbit. Their "weight" continually causes them to fall toward Earth.

What Does "Weightless" Mean?

Weight refers to the force of gravity acting on an object near the surface of a planet or star. If astronauts were not under the influence of Earth's gravity, they would fly off in a straight line into space. Therefore, astronauts are not weightless; but their weight (the force of gravity pulling them toward Earth) is what keeps them in orbit. Is it possible for astronauts to use a spring scale to weigh themselves as they move around in Earth's orbit?

Staying in Orbit

"A satellite in motion will stay in motion unless acted on by an external force." Or will it? A satellite has mass, perhaps a great deal of mass, and therefore has inertia. Once in orbit, what forces will act on the satellite? What will be required to keep it in a geosynchronous orbit?

The Cost of Altitude

Space Shuttle launches are regular occurrences, as the shuttle is the main supply vehicle for the International Space Station. Newton's 2^{nd} law accurately predicts that the more mass that is to be sent into orbit, the greater the force that will be required. Generating this force requires rocket engines and plenty of fuel. A major drawback of any concept that involves putting objects or people into space is the cost required to generate enough acceleration to put the mass into orbit.


Safety concerns surrounding life near a receiving antenna must be investigated.

Does It Really Work?

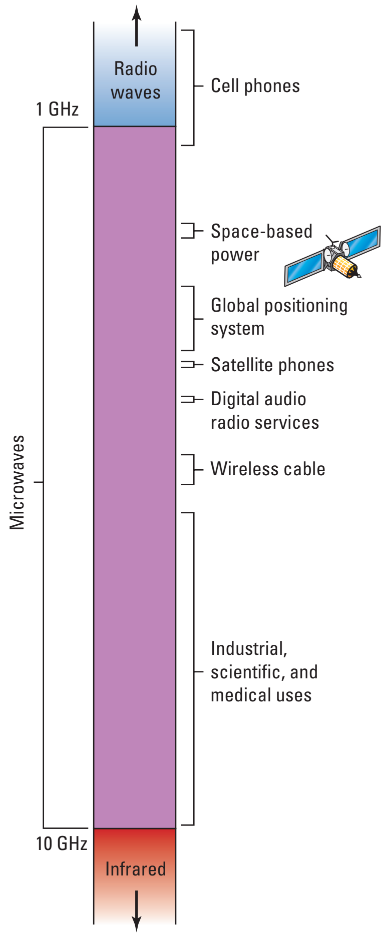
Wireless transmission of power has been experimentally verified. However, several challenges still exist. The first law of thermodynamics predicts that any energy transformation system developed will not be 100% efficient. Also, energy is required to fabricate the materials and equipment used to build the satellite and earthbound receiving station.

Wave Frequency, Energy and Safety

How much energy can microwaves carry? Can it be dangerous to human, animal or plant life? Microwaves, part of the electromagnetic spectrum, carry energy from space to Earth. Max Plank (1858–1947) suggested that the energy contained within electromagnetic radiation was related to the radiation frequency multiplied by a constant (now called Plank's constant $h = 6.63 \times 10^{-34}\ J \cdot s$). Use Plank's energy relationship, $E = hf$, to investigate the energy differences between green light ($f = 5 \times 10^{-14}$ Hz), heat or infrared radiation ($f = 4 \times 10^{12}$ Hz), and microwaves ($f = 6 \times 10^{9}$).

Interference: Communication Versus Energy Transmission

Microwaves make up a large part of the electromagnetic spectrum with frequencies ranging from about 10^{11} to 10^{9} Hz. The microwave part of the electromagnetic spectrum has been divided into small "bandwidths" for communication applications — from everyday cell phones and TV to military and space purposes. The sheer number of required bandwidth requirements has caused very tight spacing of some microwave frequencies. Signals received by an antenna from more than one source may cause effects similar to the interference patterns of superposition you saw during your study of springs.



Microwaves, the portion of the electromagnetic spectrum between Radio waves and Infrared, are used in a variety of applications.

Intensity and Power Density

Sound intensity we can hear, but what about microwave intensity? Sound intensity is sometimes given in picowatts per square metre. Health Canada standards state that exposure to 5.85 GHz

PHYSICS FILE

Astronomers at NASA once asked physicist Freeman Dyson to describe what an advanced civilization might look like. The physicist's answer points to the power of the Sun. He said:

> *"I cannot tell you what an advanced civilization would look like, because they may choose to live in unpretentious circumstances. I can tell you what an advanced technology would look like. They would almost certainly have enclosed their Sun to harvest most of its energy. All that would be left for distant viewers to see would be an infrared emitter with little visible light."*

microwaves is safe if the power density is below 10 W/m^2. How much land or water area will a receiving station require to be able to provide power to a community without endangering its nearby inhabitants?

We're Losing Power

Actually, it is not power but energy that is lost. Beaming microwaves through the atmosphere is not 100% efficient. Space-based power requires an understanding of both the wave theory and the particle theory of light. The energy loss will cause the atmosphere and surrounding area to heat up. (This effect could be used to assist in aquaculture (fish farming) if a receiving station were placed on water.)

Keeping the Mirror Clean

The land-based systems that focus light for solar thermal energy facilities on Earth are restricted by day-night cycles and bad weather. Some space-based power proposals suggest using parabolic mirrors to concentrate the solar radiation onto very specialized and efficient photovoltaic cells. Other systems would use larger panels of cheaper photovoltaic cells, removing the need for a parabolic reflector. The cheaper cells could be made from raw materials found on the moon!

From the Equator to the Poles

The ray model of light provides a very accurate method of predicting the location of images. The same process can be used to predict how the microwave beam from the satellite will strike Earth's surface at various locations. Vacationing somewhere near the equator demands much more attention to your sun block and sunlight exposure time than a destination closer to the poles. The reason lies with Earth's shape and the linear propagation of light.

Photovoltaic Alternatives

Type	Efficiency	Advantage	Application
specialized cells made from various materials	30%	can receive concentrated light focussed by several reflectors	selected locations experiencing a great deal of direct sunlight
single crystal silicon	25%	durable and long lived	satellites and industry
ploy-crystalline silicon	18%	easily deposited on glass or metal surfaces; flexible cells	small scale power generation, e.g., cottages, roadway signs
amorphous silicon	10%	easily manufactured inexpensive	calculators

Free Energy?

Solar-powered calculators, street signs, and office buildings take advantage of the unique characteristic of semiconductor materials, such as silicon. Shining sunlight on semiconductors can generate an electric current. A space-based power system captures and converts sunlight into electric energy through the use of semiconducting photovoltaic cells. The electric energy is transformed into microwaves that are beamed to Earth where they are transformed back into useable electric energy.

How Much Electric Power?

How much electric energy does a small town require in a day? You have investigated various aspects of a space-based power system. Now, it is time to investigate the feasibility of such a system in terms of power.

Wrap Up

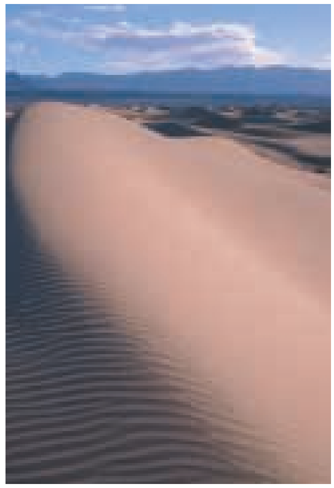
These ideas are provided to help you develop your case either for or against space-based power. You will doubtless come up with many other ideas of your own for consideration, giving your presentation its own unique characteristics.

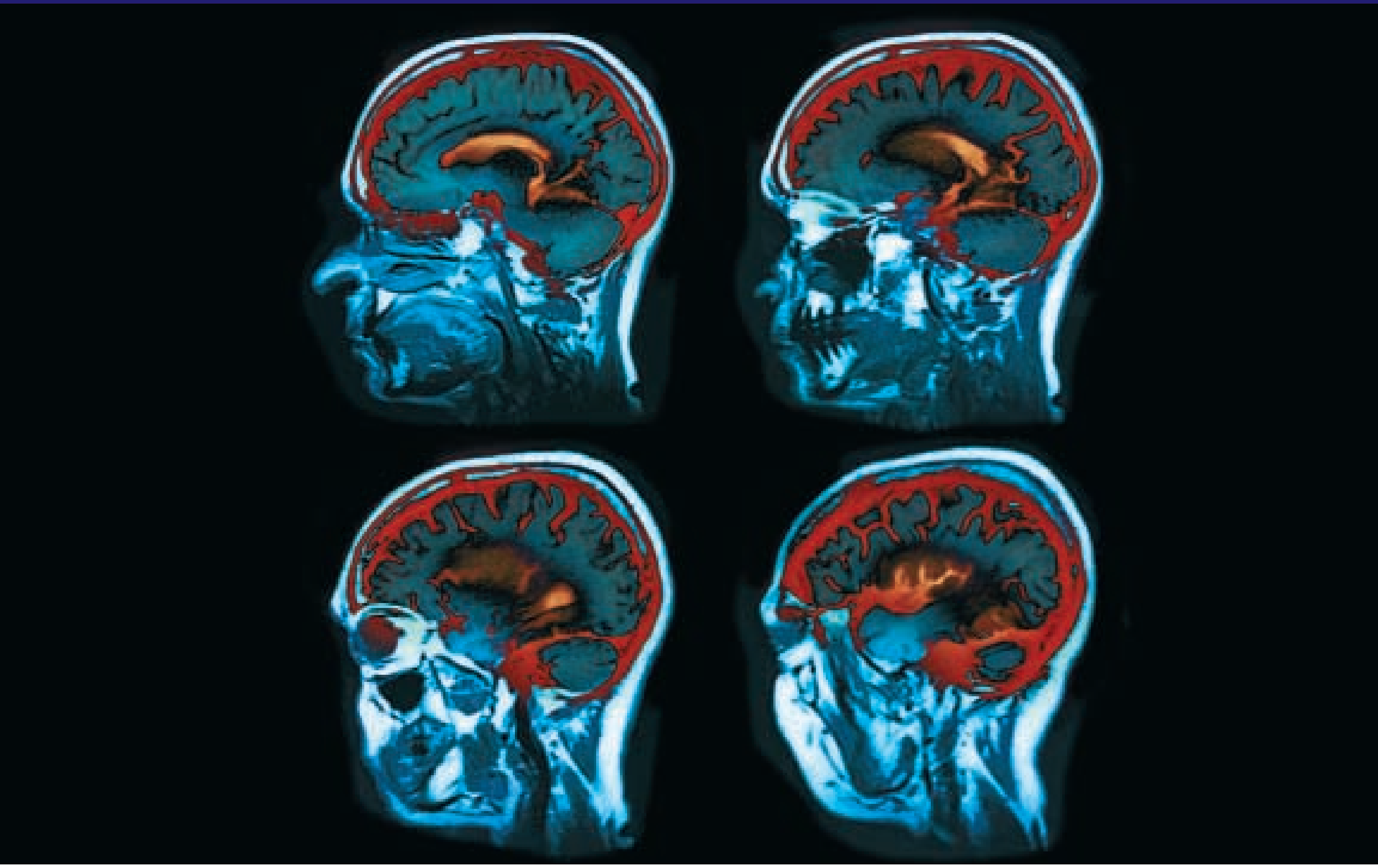
This brief tour has included some of the factors to consider about space-based power as a possible future energy source, as well as ideas about your own presentation of a case for or against it.

We are living during a time when scientific knowledge and technology may together provide important solutions to global energy needs. The potential for sustainable power production by using a variety of energy sources has only recently become possible. Today, new choices can be considered because of advancement in technology and deeper scientific understanding of our world, from the nature of ecosystems to the operation of rockets. Your own thorough investigation of this one possible energy source — solar-based power — will give you a better understanding of how it may or may not be a viable alternative to energy sources currently being used.

PHYSICS FILE

Alternative energy sources, such as wind-based power, are often criticized for occupying large areas of land. Space-based power greatly reduces this problem by placing photovoltaic panels in orbit. The receiving antennas, however, still require sizable portions of land. There are cost and logistical problems associated with constructing a receiving antenna in a remote region, such as the desert shown below. However, unlike hydro-electric and wind-power installations, the location of the antenna is not dependent on geographic features. Rather, it can be placed in a location that takes into consideration environmental and other factors.





These magnetic resonance imaging (MRI) scans reveal four profile views at different depths of a healthy human brain. The folded cerebral cortex — associated with thought processes — is highlighted in red.

Scanning Technologies: Today and Tomorrow

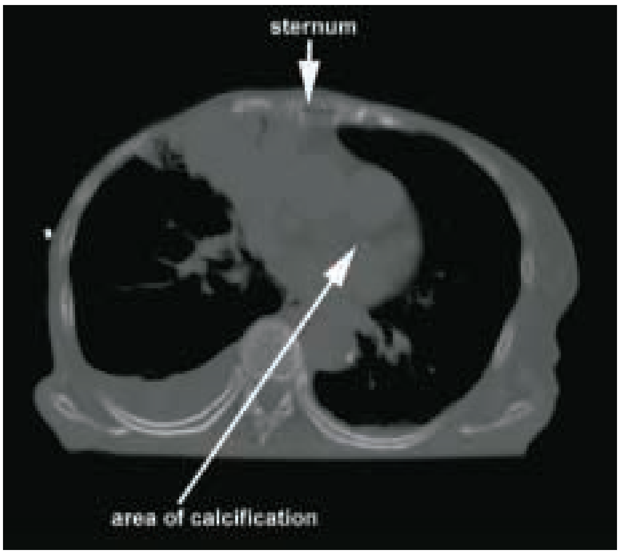
An X-ray image of a tooth or broken bone is commonplace, and ultrasound images of a developing fetus are a regular part of prenatal care. Without the need for a single incision, various forms of non-invasive imaging technology provide clear images of the soft tissues of our bodies. Imaging technology also exposes the contents of locked luggage during airport security checks. Satellites circle Earth, relaying data about geological changes, volcanoes, hurricanes, and crop and vegetation densities.

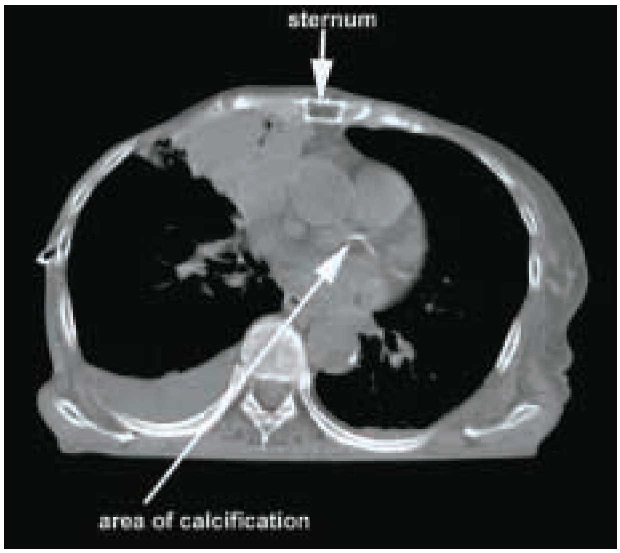
Understanding the fundamental properties of matter, fields, waves, and energy has opened the door to hundreds of scanning technologies, and continuing research results in yet more scanning methods and continues to push the capabilities of these technologies to new heights. Research costs money, however, and is very time-consuming. Are these new scanning techniques worth the expense and time involved?

This Course Challenge prompts you to examine the costs and benefits of imaging technologies to both the scientific community and society. To help you get started, three fields of scanning technology and some associated issues are presented here.

Medical Issues

Doctors and politicians are often criticized when professional athletes gain access to magnetic resonance imaging (MRI) diagnosis immediately after sustaining an injury, while the general public must often wait months. Questions arise about the real expense of MRI equipment, its availability, and the value of the results as compared to other methods. How does an MRI machine work? What fundamental principles of nature does it exploit? Why is MRI scanning so expensive? Will the costs reduce with time? Will the technology improve with time? Are there better, less expensive options that should be pursued? Will this technology ever be made available to citizens of developing nations? To develop an argument supporting continued use of and research into MRI technology, you need to be able to answer these and other questions.





Motion, such as a beating heart or breathing, causes a blurring of conventional computerized tomography (CT) scan images. New computer technology, involving millions of frames of reference calculations, is able to remove the blur and produce much clearer images.

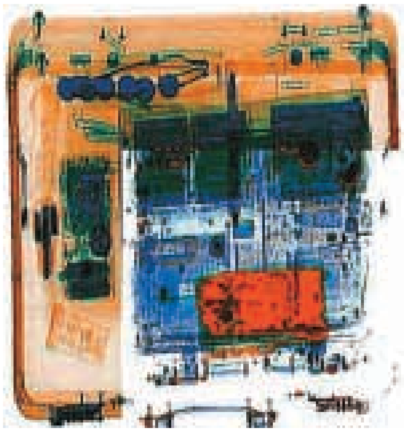
Photos courtesy of Dr. S. Stergiopoulos, Defence R&D Canada - Human Sciences, Toronto, Canada

PHYSICS FILE

A remote mountaintop in western North America rose 10 cm in four years, from 1996 to 2000. The 10 cm bulge is at the centre of a circle with a 12 km radius, and is only a few kilometres from the South Sister, a volcano that erupted 2000 years ago. The bulge is believed to be the result of growing pressure in an enormous chamber of magma beneath the mountain, and a telltale sign of potential volcanic activity. The 10 cm shift is a very small indicator of the tremendous amount of energy behind it, and would never have been detected without the remote-sensing ability of Earth-orbiting satellites.

Security Issues

Border-crossing and airport security often rely on technology to solve problems associated with screening large numbers of people and baggage in an efficient way. Some debate the effectiveness of the technological solutions compared to the enormous costs required to install and maintain the equipment. Opponents suggest that a human work force could do a more thorough and efficient job. Developing an argument supporting either side of this debate requires an in-depth understanding of the technology and its capabilities, and perhaps even a sense of its future potential.



A security imaging system can be set to detect the presence of explosives, narcotics, currency, or gold. In this case, the computer analyzed the contents of a laptop computer case and identified explosive material, indicated by the bright red area in this scan image.

Space Issues

Earth-orbiting, satellite-scanning technologies are used for environmental data collection, which is required for the development of sustainable agricultural, industrial, and even population-settlement plans. Weather satellites have allowed meteorologists to dramatically improve their forecasts. Surveillance satellites provide governments with information about covert operations.

A wealth of information comes from space, but the launching and maintaining of satellites is extremely expensive. World citizens need to be convinced that the economic costs associated with space-based research and related technologies are worth the rewards.

The Canadian Space Agency (CSA) and the U.S. National Aeronautics and Space Agency (NASA) devote a substantial amount of effort to global education, providing evidence of the benefits of space-related research. These agencies also work diligently to include other nations in large projects, such as the International Space Station. The CSA and NASA also recognize that projects must offer the global business community financial opportunities, as well as knowledge, to be successful in the long term. Does the commercialization of space fit with your vision of the future?

Debating which technologies are worth the investment of monetary and human resources can be accomplished only when all of the facts are known. Think about these questions as you undertake this Course Challenge.

Challenge

Develop and present a case either for or against the use of a particular scanning technology. You will use the knowledge and concepts you have acquired throughout this course, along with additional research, to develop your presentation about the economic, social, or environmental viability of a medical, industrial, or environmental scanning technology. Your class will decide together whether the presentations will be made through

- a formal debate
- research report presentations (either as a written report, an audiovisual presentation, or an information billboard)
- another format of your choice

Materials

All presentations are to be supported by your portfolio of research findings, the results of supporting experiments conducted, and a complete bibliography of references used.

Design Criteria

A. You need to develop a system to collect and organize information that will include data, useful mathematical relationships, and even questions that you use to formulate your final presentation near the end of the course. You can collect your own rough notes in a research portfolio.

B. Building a Research Portfolio
Your individual creativity will shape the amount, type, and organization of the material that will eventually fill your portfolio. Do not limit yourself to the items mentioned in the Course Challenge cues scattered throughout textbook; if something seems to fit, include it. The following are suggested items for your research portfolio.

- experiments you have designed yourself, and their findings
- useful equations
- specific facts
- interesting facts
- disputed facts
- conceptual explanations
- diagrams
- graphical organizers
- useful Internet site URLs
- experimental data
- unanswered questions
- pertinent economic or social statistics (Canadian or global)

C. As a class, decide on the type(s) of assessment you will use for your portfolio and for its presentation. Working with your teacher and classmates, select which type of presentation you will use to present your scanning technology arguments.

Action Plan

1. As a class, have a brainstorming session to establish what you already know and to raise questions about various scanning technologies that are currently being used or researched today. For example, what medical value does an MRI offer over other diagnostic methods, and is that difference worth the economic price? How widely available is MRI technology in **(a)** Canada or **(b)** other parts of the developed or underdeveloped world?
2. As a class, design an evaluation scheme, such as a rubric or rubrics for assessing the task. You could decide to assess specific components leading up to the final presentation, as well as the presentation itself.
3. Decide on the grouping, or assessment categories, for this task.
4. Familiarize yourself with what you need to know about the task that you choose. For example, if you choose a debate, it is important to research the proper rules of debating in order to carry out the debate effectively.
5. Develop a plan to find, collect, and organize in your research portfolio the information that is critical to your presentation.
6. Carry out the Course Challenge recommendations that are interspersed throughout the textbook wherever the Course Challenge logo and heading appear, and keep an accurate record of these in your portfolio.
7. When researching concepts, designing experiments or surveys, or following a Course Challenge suggestion in the textbook, you might find that the McGraw-Hill Ryerson Internet site is a good place to begin: *www.mcgrawhill.ca/links/atlphysics*
8. Carry out your plan, making necessary modifications throughout the course.
9. Present your arguments to your class. Review each presentation against the assessment criteria that you decided on as a class.

Evaluate Your Challenge

1. Using the assessment criteria you have prepared, evaluate your work and presentation. How effectively did your portfolio and presentation support your arguments? Were others able to follow your line of reasoning, based on the evidence, results, and conclusions you presented? How would you revise your presentation?

2. Evaluate your classmates' Course Challenge presentations.
3. After analyzing the presentations of your classmates, what changes would you make to your own project if you had the opportunity to do it again? Provide reasons for your proposed changes.
4. How did the process required to complete this challenge help you to think about what you have learned in this course?

Background Information

The following sections provide ideas to consider. They are linked to topics covered in the course and relate to the Course Challenge cues in your textbook. Your arguments will be both strengthened and redirected as you gain knowledge from each unit in this course.

Frames of Reference

Describing motion in two and three dimensions requires the use of vector quantities. Consider the scanning technology that you have selected for investigation. How is an image obtained? Does the scanning machinery move, or does the item that is being scanned move? Does the technology detect motion or the change in orientation of atomic and subatomic particles? Analyze the scanning technology you are investigating from the perspective of frames of reference. Develop a comprehensive description detailing how an image is formed based on the location of particles in a two- or three-dimensional space.

Momentum

The conservation of momentum is the principle that allows navigation in space. Conservation of momentum is a fundamental property of our universe. Conservation of momentum applies to planetary, human, and subatomic levels. Investigate possible applications of momentum conservation used in the scanning technology that you are investigating. If the conservation of momentum applies only to atomic and subatomic interactions, you might want to complete your analysis during your study of Unit 7, Waves and Modern Physics, in the textbook.

Energy Transformations

Producing scanned images requires very controlled energy transformations. Investigate the energy path used by the technology you have chosen to investigate. Answer questions such as: What energy is directed at the item to be scanned? Is energy absorbed, transmitted, or both? What energy transformations occur within the scanned item? What energy transformations occur at the scanning receiver? Support your presentation with quantitative energy transformation analysis. Is there an economic, social, or safety aspect relating your technology to energy transformation issues?

Contact versus Non-Contact

You might want to compare contact versus non-contact forces. A century ago, a medical examination conducted to identify an abnormal growth would have involved physical contact, because the doctor used touch to assess the patient. Current medical examinations are able to obtain a much clearer picture of an abnormal growth inside the body without ever coming into direct contact with the patient. Consider the scanning technology you have chosen in these terms.

Field Energy

Ultimately, the energy stored in fields will be the basis for the operation of any scanning technology. Satellite-based technologies orbit Earth, held in position by the gravitational field. Medical scans employ powerful magnetic fields to obtain diagnostic imagery. Investigate how fields play a role in the production of images in the technology that you are investigating. You might want to consider your technology in terms of a quantitative application of Coulomb's law.

Waves and Particles

Scientific models evolve when theories are modified and validated by new experimental results. Physicists realize that electromagnetic radiation can be fully described only by using two completely different scientific models. Models are made by humans and therefore change as more knowledge is acquired. You might be able to demonstrate that a complete description of your chosen scanning technology requires both the wave and particle nature of electromagnetic radiation.

Nuclear Energy

Nuclear energy provides electrical power not only to our homes, but also to most of the satellites orbiting overhead. Nuclear energy is used to probe living tissue in a variety of medical scanning technologies. Investigate nuclear decay rates of various materials and how they relate to your scanning technology. You might want to introduce safety and societal issues related to the use of nuclear material in the technology that you are investigating.

Wrap-Up

These ideas and questions are provided to help you develop your arguments related to a specific scanning technology. The ultimate shape of your presentation will be determined by the technology you choose to investigate, the issues you choose to address, and your own creativity. In order to prepare a high-quality, in-depth presentation, you will need to limit the amount of information that you attempt to present, focussing on the key points. Attempt to support your ideas with experimental evidence, mathematical verification, and comparisons to accepted scientific models. Give your project added relevance by relating your topic to key societal issues, such as economic or safety considerations.

Use your Course Challenge presentation to assist your learning by drawing together topics from each unit of study. As is often the case with any issue, the quality of discussion improves when knowledgeable links are made between topics.