chapter 1

Radiation-Based Diagnostic Technology

Prior Knowledge: The Bohr Model of the atom was introduced in Grade 9 science. As well, the four fundamental forces were introduced in Grade 11 physics. Students should recall the formula relating velocity, frequency and wavelength from Grade 11 physics ($v=\lambda f$), as well as the measurement units for frequency (Hertz).

Terms You Should Know: The list below highlights important terms beyond what is listed at the end of the chapter in the Student Resource. Teachers could use either list as a knowledge activation activity—have students create a concept map or definitions frame—or as a review of concepts.

**Note that this list of terms is not intended to be a list for memorization. It is here to help the teacher incorporate new concepts into activities.*

alpha decay	hemorrhage
alpha particle	Hertz (Hz)
arthrography	hot spot
attenuation	isotope
benign	mammogram
beta decay	mammography
beta particle	N-ray
calcification	PET (Positron Emission Tomography)
cathode ray tube	photon
CT (Computed Tomography)	positron
CT scanner	radiation
cold spot	radiograph
density	radiopharmaceutical
electromagnetic radiation	radiotracer
electromagnetic spectrum	subdural trauma
electromagnetic wave	tomograph
electron	tomography
electron-volt (eV)	transmutation
frequency	tumour
gamma ray	wavelength
health physics	x-ray
	UV radiation

Chapter Summary: This chapter introduces the concept of X radiation and three types of diagnostic technology that use X radiation: Positron Emission Tomography (PET), Computed Tomography (CT), and the X Ray machine.
The chapter includes a brief review of the electromagnetic spectrum.

Blackline Masters/Enlarged Images: At the end of this set of answers and solutions to chapter 1's questions, there are enlarged images from the Student Resource guide, ready for either projection (display) or photocopying.

activity

Page 3 | Tissue Attenuation"

How much light goes through the single layer of tissue paper will depend on the thickness of the paper and on the brightness of the flashlight. Tissue paper thickness relates to human tissue density (for x-rays). Brightness of the flashlight relates to energy levels of the x-rays: the brighter (or more energetic) the rays are, the more they get through. (This does not necessarily mean that a clear image of tissue will be produced with more energetic x-rays!) Less light should travel through the double layer of tissue paper than the single layer. The more dense the material, the less light rays travel through. In a similar fashion, the more dense the tissue is, the less x-rays travel through and the darker the area on the radiograph.

Page 7 | "Questions: Electromagnetic Spectrum"

❶ Calculate the wavelength of sound waves that an FM radio station broadcasts using 88MHz broadcasts.

Students should recall the formula v=λf.
Solving for λ... λ = v/f = (343 m/s)/(88 000 000 Hz) = 3.90×10^{-6} m

❷ What is the difference between "soft" and "hard" x-rays (mentioned in Figure 1-2)?

Soft x-rays have lower energy and longer wavelengths than the higher energy shorter wavelength hard x-rays. X-rays with energies between 10 keV and a few hundred keV are considered hard x-rays. Soft x-rays have less than 10 keV of energy.

❸ What is the wavelength used by cell phones compared to the wavelength of PET scans? Which carries more energy?

The wavelength of cell phones is approximately 0.3 metres, and their frequency ranges from 800 to 900 MHz. Different cell phone companies use different "bands" or ranges of frequencies. PET scanners use gamma (γ) radiation with a wavelength of below 10 picometres (1 picometre = 10^{-12} metres) and a frequency of between 1018 and 1021 Hz. Gamma radiation carries more energy than that used by cell phones.

❹ What is the difference between UV-A and UV-B light?

UV-A light has wavelengths between 315 and 400 nm and is sometimes referred to as "long wave" ultraviolet light. UV-B light has wavelengths between 280 and 315 nm and is "medium wave" UV light. UV-A light is considered the safest of the three types of UV light because it has lower energy and longer wavelengths than UV-B. The higher energy and shorter wavelengths in UV-B can cause sunburns and damage collagen. UV-A light can cause DNA damage, but only indirectly. UV-A light's longer wavelength means less of it is absorbed by the skin, but still has the potential to speed up skin aging and cause wrinkles.

❺ What is the difference between sound waves we hear and ultrasound?

Ultrasound involves a repeated cycle of sound with a frequency of 20 kHz, higher than the upper limit of human hearing. This sound cycle can be used to reflect off of objects and is used in sonography to produce images. Humans can hear sound with frequencies between 20 Hz (a low bass note) and slightly less than 20 kHz. The range of frequencies that can be heard varies from person to person, with younger individuals usually having larger ranges and the ability to hear higher and lower frequencies.

Page 8 | "Research Questions"

Why use iodine in arthrography and not other elements? What does calcification mean?

Iodine is used in arthrography because it is a dye which is both air and water soluble. Arthrography involves x-rays of joints, which can either be fluid-filled or not. Thus, iodine is an appropriate choice due to its solubility: it is also economical. Calcification is another term for the hardening of tissue due to calcium deposits. Calcification can show up on an x-ray.

Page 9 | "Question"

Note that the wrist joint of Figure 1-3 is brighter than the finger joints. What does this tell you about comparative bone densities or thicknesses? *Brightness on x-rays indicates less dense material. Therefore, the wrist joint for this individual is either less dense than, or not as thick as, the finger joints on this radiograph.*

Page 10 | "Activity: X-Ray Analysis"

Below are nine different x-rays of various parts of the human body. Imagine you are the x-ray technician asked to analyze each radiograph. Do you see something that is unusual? What do the unusual sections potentially indicate? Why are some areas of the x-rays brighter? For each image, discuss with your class whether the differences in brightness are more likely due to density, thickness, or the nature of the material (attenuation coefficient).

In general, the more dense tissue will be shown by darker areas on each of the images. Brighter x-rays indicate images taken of less dense tissue or bone, or of a radiotracer enhancing the image.

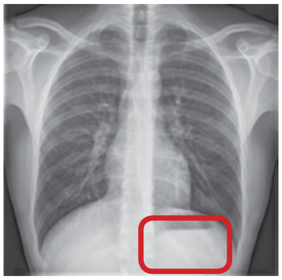

Figure 1-5

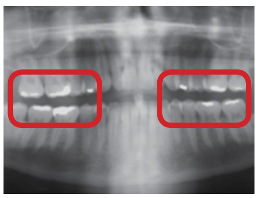

Figure 1-6/1-7

Figure 1-8

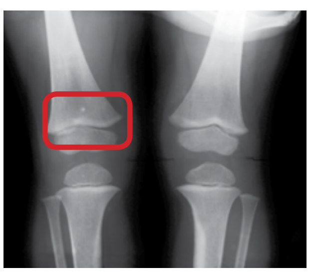

Figure 1-9

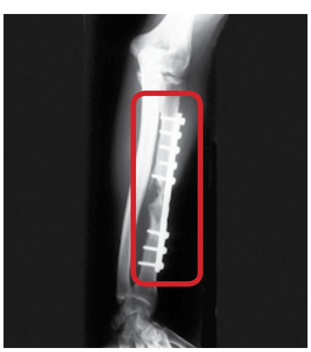

Figure 1-10

Figure 1-5: shows no broken bones. Shadow area at bottom right of x-ray may be cause for analysis—darker area means more density, and may indicate possible tumour growth.

Figure 1-6 (molars): show healthy roots and no bright areas indicating fillings.

Figure 1-7 (panoramic dental): teeth all seem to have healthy roots, however individual obviously has fillings on top and bottom teeth (bright spots).

Figure 1-8 (forearm): this x-ray confirms that there is a fracture to the forearm (broken bone!). Note—an interesting side note for students would be to compare figure 1-8 with figure 1-4. Both are images of wrists, however the bones are very clear in 1-4 and not clear in 1-8. The image in 1-8 is of a child's wrist, whereas the image in 1-4 is of an adult's wrist. You may want to point out that the bones in the child's wrist have not yet formed and are still mostly cartilage.

Figure 1-9 (knees): colouration all similar except for one bright spot on top left—calcification maybe? (Explain to students that calcification is a process where calcium builds up in soft tissue, causing it to harden.)

Figure 1-10 (forearm): this x-ray shows a broken forearm with a splint –attached by eight screws.

Figure 1-11 (colon): colon (on the right of the image) indicates no obvious change in colour. The left of the image shows the spine of the individual—no broken bones!

Figure 1-12 (skull): image shows no fractures in skull structure. Students may ask why there is a bright spot in the central brain area. This individual has ingested a contrast agent which travels through the blood stream and can help indicate bloodflow patterns in the brain if a functional MRI (fMRI) is performed.

Figure 1-13 (breast): the brighter circle on this image can indicate calcification (as in image 1-9) or a possible tumour. Further analysis, such as a biopsy (surgery to obtain sample of the area), would have to be done to be more definitive in the analysis. Ultrasound is also useful in determining if a structure such as this is fluid filled or a solid mass.

Figure 1-11

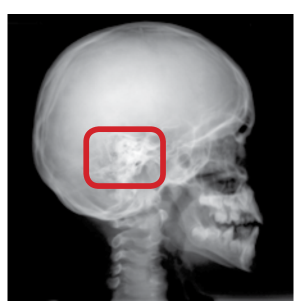

Figure 1-12

Figure 1-13

activity

a PET Radiotracer jigsaw

Your teacher will divide the class into four different groups. Each group will be assigned one of the questions below to research. Each group member should take notes and be prepared to explain the concepts.

1. How are each of the four radiotracers used for PET scans created? Which country (or countries) produces them?

2. If the process is called Positron Emission Tomography, why does the technology measure gamma rays and not positron emissions?

3. Technicians look for "hot spots" on the PET scans as well as for areas of inactivity or "cold spots" (blue/green areas). What types of body functions or diseases can hot spots (red/orange areas) potentially indicate other than cancerous tissue? What types of body functions or diseases can cold spots indicate to the technician?

4. Two photons per atomic decay are emitted, striking detectors mounted on linearly opposite sides of a ring that surrounds the patient in the PET scanner. How does conservation of linear momentum explain the motion of these two photons?

Once each group has completed their research and note-taking, your teacher will redistribute you into new groups of four people each. Each of the new groups will contain one person from each of the old groups. When you share your research results in your new group of four people, you should have a complete set of answers to the four questions.

Page 12 | "Research Questions: Mammography and Alternatives"

What exactly does a positive test result mean for a mammogram? (Cancer? A calcium deposit? A benign tumour? Something else? All of the above?)

A positive test result on a mammogram means that there is an abnormality on the x-ray. An abnormality must be analyzed further to determine whether it is calcification, a benign tumour, a malignant (cancerous) tumour, or simply an artifact.

What other types of diagnostic technologies could be used to confirm or deny the positive test results?

Other forms of technology used to confirm or deny positive test results include having a biopsy done, where a sample of the abnormality or growth is surgically removed and analyzed further. Doctors could order other diagnostic tests such as a CT scan or an MRI to obtain a better image of the abnormality for analysis.

Research and compare rates of breast cancer in males and females of similar ages. Are they the same or different? Why?

According to the Canadian Cancer Society, an estimated 22,400 women were expected to be diagnosed with breast cancer in 2008 and some 5,300 would eventually die from it (Canadian Cancer Society, 2008). An estimated 170 men would be diagnosed with breast cancer and 50 will die of it. Students can go to www.cancer.ca to find provincial and national breast cancer statistics. Men have breast tissue just like women, and can develop breast cance though rarely. The rate of breast cancer in men is much lower, however. It is thought that the reason for this disparity is because men do not have the breast tissues per se that in women are the chief locations of tumour growth. For instance, cancer cells may thrive within the ducts (this is called ductal carcinoma) or in the lobules (lobular carcinoma). Ductal carcinoma is the most common type of breast cancer., The hormonal complexity of a woman's physiology may offer a hidden pre-cursor to cancer development as well, though not substantiated.

Page 15 | "Activity: X-Rays and CT Scans—The LINKs"

Many answers are possible.

"Activity: A PET Radiotracer Jigsaw"

1. How are each of the four radiotracers used for PET scans created? Which country (or countries) produces them?

   Oxygen-15 (15O), nitrogen-13 (13N), carbon-11 (11C) and fluorine-18 (18F) are all created by the same general process. A "mini" cyclotron (room-sized) is used to accelerate negative hydrogen ions and impart large amounts of energy to them. Once optimum energy levels are reached, the hydrogen ions are sent through carbon filters to strip them of their electrons. This converts them into a beam of protons which can be directed at a target. The target is usually a stable form of the isotope desired.

   Oxygen-15 has a half life of under two minutes; nitrogen-13 has a half life of under ten minutes; carbon-11 has a half life of under twenty minutes; fluorine-18 has a half life of under two hours.

   Water containing oxygen-15 (the radioactive isotope of oxygen) is used as a blood-flow tracer. Fluorine-18 is typically placed in a sugar-water mixture and used to analyze brain activity and cancerous growths. Ammonia containing nitrogen-13 is often used for heart research.

   The highest resolution PET scanner can be found at Berkeley Labs in California, where the first cyclotron was created. Canada has over a dozen facilities with PET scanners and cyclotrons used to produce the radiotracers used with this technology. The positron emitting isotopes used in PET have a very short half-life and are ideally produced onsite with a cyclotron. If there is no onsite cyclotron, a maximum travel time of only a few hours can be tolerated.

2. If the process is called Positron Emission Tomography, why does the technology measure gamma rays and not positron emissions?

A positron is the antimatter particle of the electron. It has the same mass as an electron but has a charge of +1. In positron emission tomography, a radiotracer is used that decays by emitting a beta-plus particle (positron) and gamma radiation. Though the process involves creation of positrons, the technology (PET scanner) registers the emissions of gamma rays by the radioactively decaying radiotracer.

3. Technicians look for "hot spots" on the PET scans as well as for areas of inactivity or "cold spots" (blue/green areas). What types of body functions or diseases can hot spots (red/orange areas) potentially indicate other than cancerous tissue? What types of body functions or diseases can cold spots indicate to the technician?

PET scans are used to analyze brain functioning or brain activity. The radiotracers used collect in areas of activity. Thus, hot spots can indicate areas of high activity, which could mean that a lot of energy is being used to create cancerous cells.

Hot spots can also indicate areas of high brain activity. Researchers can use this trait to determine the levels of activity or functionality of different areas of the brain when, say, a person is attempting to do mathematical calculations, or which areas of the brain become active when speech occurs. Cold spots, alternatively, can indicate lack of brain activity. Researchers studying Alzheimer's Disease have used PET scans to determine which areas of the brain are no longer functioning for patients with this disease.

4. Two photons per atomic decay are emitted, striking detectors mounted on linearly opposite sides of a ring that surrounds the patient in the PET scanner. How does conservation of linear momentum explain the motion of these two photons?

Total linear momentum of a system remains constant because of the law of conservation of momentum. The total momentum of the isotope before decay will equal the total momentum of the two released photons after decay. The two photons travel in opposite directions and strike oppositely located detectors: because they travel in opposite directions with equal momentum, there is a total linear momentum of zero. They must have a total momentum of zero after decay because before decay the isotope has a total overall momentum of zero.

"Activity: The Great Debate Should Patients Have the Right to Choose?"

Many answers are possible.

activity

THE GREAT DEBATE Should Patients Have the Right to Choose?

Based on the opposing viewpoints offered in this chapter, think about what you would do if faced with a decision whether to have certain of these diagnostic procedures in your own diagnosis. If it were possible, would you request the use of technology not involving ionizing radiation? Why (not)? Would you allow radiation-based technology to be used if that was the only way to obtain an effective image for proper diagnosis? Do the benefits of using radiation-based technology outweigh the risks? Should this type of health care service be free, or should patients pay extra for what can be expensive diagnostic procedures and treatments? Be prepared to justify your opinion.

Your teacher may set up the class into two opposing groups for a debate to either defend or refute the following statement:

"Patients should have the right to refuse the use of radiation-based diagnostic technologies during their own diagnoses. If they are given the right to choose the diagnosis technique, then they should have to pay for it too."

extra chapter follow-up questions

1. How does an atom become ionized?
2. Define non-ionizing radiation.
3. List examples of non-ionizing radiation.
4. List examples of ionizing radiation.
5. Does infrared light affect humans? Explain.
6. Do microwaves burn deep-tissue? Explain.
7. What are the three types of UV rays?
8. Which UV ray causes the most human sun damage?
9. Which UV ray causes the most aging of skin?
10. Does sunscreen protect from all 3 types of UV rays? Explain.
11. Define ionizing radiation.
12. Explain how these particles are related to ionizing radiation: alpha particles, beta particles, neutrinos.
13. Is ionizing radiation damaging to a human? How?
14. Define gamma radiation.
15. How can you mathematically determine the amount of gamma radiation a substance will absorb?

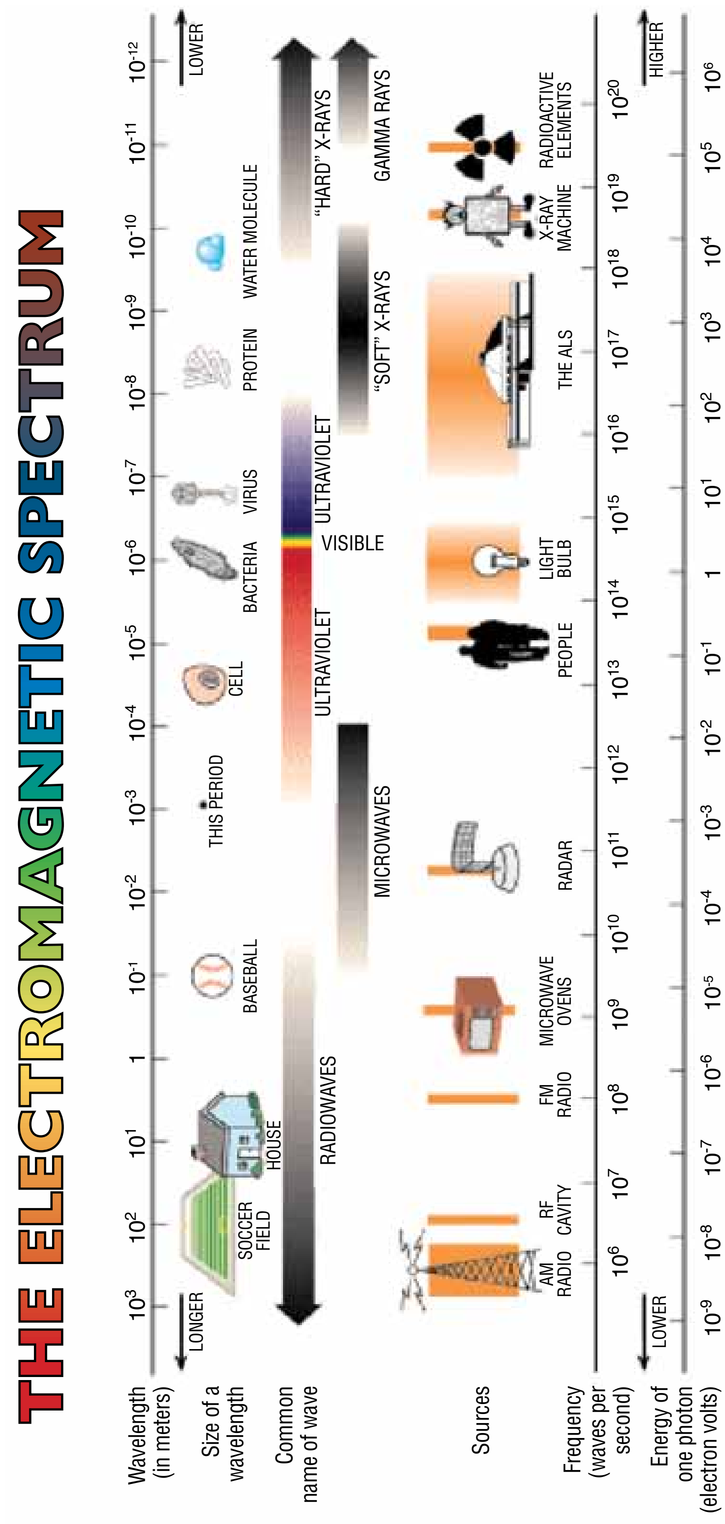
THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11 10^-12
LONGER
LOWER
Size of a wavelength
SOCCER FIELD
HOUSE
BASEBALL
THIS PERIOD
CELL
BACTERIA
VIRUS
PROTEIN
WATER MOLECULE
Common name of wave
RADIOWAVES
MICROWAVES
INFRARED
VISIBLE
ULTRAVIOLET
"SOFT" X-RAYS
"HARD" X-RAYS
GAMMA RAYS
Sources
AM RADIO
RF CAVITY
FM RADIO
MICROWAVE OVENS
RADAR
PEOPLE
LIGHT BULB
THE ALS
X-RAY MACHINE
RADIOACTIVE ELEMENTS
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20
LOWER
HIGHER
Energy of one photon (electron volts)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6
LOWER
HIGHER

Figure 1-5 enlarged

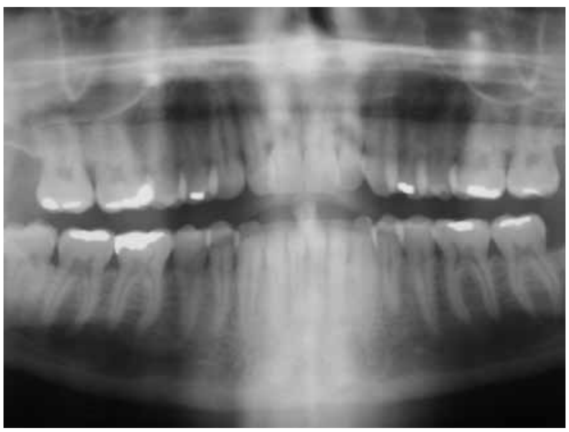

Figure 1-6 enlarged

Figure 1-8 enlarged

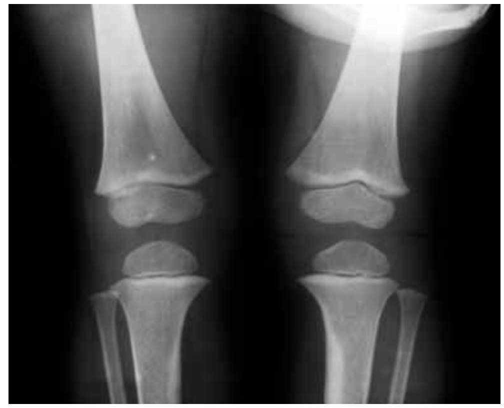

Figure 1-9 enlarged

Figure 1-10 enlarged

Figure 1-11 enlarged

Figure 1-12 enlarged

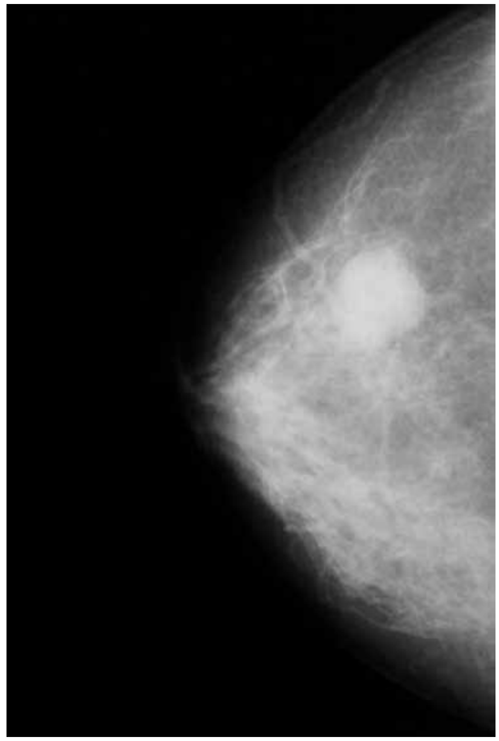

Figure 1-13 enlarged

The image here is of a "creation mural" inside one of the schools in Pripyat, Ukraine. The photograph was taken in 2003 by Winnipeg arts professor Dr. David McMillan, who has an interest in documenting the "return to nature" of the human-constructed world in and around the Chernobyl nuclear power facility . The so-called 30-kilometere Exclusion Zone surrounding the science city of Pripyat is still so radioactive, humans cannot live there for the foreseeable future. This is a good opportunity to assess the benefits and risks of operating a nuclear facility without the necessary safeguards against the release of radioactive isotopes. Many more images and commentary can be found online at:
http://home.cc.umanitoba.ca/~dmcmill/index.html