A Guide to Electromagnetic Radiation

Teaching Approach

This section is allocated 3 ½ hours of curriculum time so this limits the depth you can go to in the content. The students need to watch the videos in their order, Lesson 1 first, and so on. The videos have only a few questions in them so make use of the task video to ensure that the students exercise the ideas you are teaching them through the Mindset lesson videos.

Key ideas in the topic are:
1. Electromagnetic radiation is emitted from electrons that are oscillating — that is, it's emitted from electrons that are being accelerated, first one way and then the other.
2. The radiation has a frequency and wavelength that is determined by the frequency of the electrons' oscillations.
3. The radiation travels away from the source at the speed of light.
4. The frequency and wavelength of radiation are locked together through the relationship $c = \lambda f$, where c is the speed of light. If the electrons' frequency f increases, then wavelength λ decreases because c remains constant.
5. Electromagnetic radiation can transfer the energy of the oscillating electrons through empty space (or through certain materials) into any material or device that can absorb energy at that frequency. (Try to avoid saying that the radiation is energy itself; it's more accurate to say that the radiation **transfers the energy** of one system to another system.)
6. The electromagnetic spectrum is the range of all frequencies (and therefore wavelengths) of the radiation; the Lesson 4 video shows frequencies from low radio wavelengths, through visible light, to extreme gamma-ray frequencies.
7. Different materials and devices (such as cell phones) respond to particular frequencies. This can be useful in many cases. On other cases the material can be altered or damaged by the radiation.

The approach is to begin with the devices that students know such as cell phones and remote controls and microwave ovens. Explain the word "radiation"; students may associate the "radiation" with nuclear bombs but reassure them that there are many kinds of non-harmful radiation all around us all the time.

We can sense some radiation with our bodies: our eyes respond to light, our skin to infrared immediately and, in the case of sunburn, skin responds to ultraviolet radiation (and remind them that black skin is also affected by ultraviolet radiation though to a lesser extent than white skin.)

But for almost all the other frequencies we do not sense most of this radiation, because we do not have the nervous system to do so. Radios and cell phones (which are small radios) respond to other frequencies of electromagnetic radiation.

CAPS specifies that this topic must be taught in Term 1 but does not introduce the magnetic field until Term 2 and electric fields until Grade 11. So in Lesson 2 and 3 we have to give some meaning to the CAPS statements about mutually regenerating electric and magnetic fields. There is some very simple apparatus you can make that will help explain what happens when electrons are accelerated up and down a conductor.

Video Summaries

Some videos have a 'PAUSE' moment, at which point the teacher or learner can choose to pause the video and try to answer the question posed or calculate the answer to the problem under discussion. Once the video starts again, the answer to the question or the right answer to the calculation is given

Mindset suggests a number of ways to use the video lessons. These include:

- Watch or show a lesson as an introduction to a lesson
- Watch or show a lesson after a lesson, as a summary or as a way of adding in some interesting real-life applications or practical aspects
- Design a worksheet or set of questions about one video lesson. Then ask learners to watch a video related to the lesson and to complete the worksheet or questions, either in groups or individually
- Worksheets and questions based on video lessons can be used as short assessments or exercises
- Ask learners to watch a particular video lesson for homework (in the school library or on the website, depending on how the material is available) as preparation for the next day's lesson; if desired, learners can be given specific questions to answer in preparation for the next day's lesson

1. Electromagnetic Waves All Around Us

Electromagnetic radiation is all around us. The lesson focuses on radio waves to remind students of the concepts of frequency and wavelength, and ends with the speed of electromagnetic radiation, which is the same as the speed of light.

2. Electric and Magnetic Fields

A changing electric field generates a changing magnetic field. The changes at a source will take a certain time to travel to a distant point. This lays the groundwork for Lesson 3, which is about how electromagnetic waves propagate.

3. How Vibrating Charges Emit Electromagnetic Waves

This lesson uses a simple antenna system to show how a changing electric field causes a changing magnetic field to propagate outward from the antenna. The changes in the fields travel outwards from the transmitter at the speed of light.

4. The Electromagnetic Spectrum

A wide range of frequencies form the electromagnetic spectrum; they are arranged from low radio frequency to the very high frequencies of gamma rays. The lesson gives examples of how they are detected and how they are used.

5. The Energy of Electromagnetic Radiation

This lesson shows the uses of electromagnetic radiation at different frequencies. It deals with the actual danger of very high frequency, high energy radiation.

Resource Material

1. Electromagnetic Waves All Around Us	http://www.bbc.co.uk/schools/gcsebitesize/science/aqa_pre_2011/radiation/anintroductiontowavesrev1.shtml	This web page has a useful summary of waves, including radio waves, with animations to play. It has exercises using the wave speed equation, and students can take a test at the end.
2. Electric and Magnetic Fields	http://missionscience.nasa.gov/ems/02_anatomy.html	A good overview of fields and electromagnetic waves.
3. How Vibrating Charges Emit Electromagnetic Waves	http://missionscience.nasa.gov/ems/05_radiowaves.html	Some history of radio waves and then looks at radio waves coming from deep Space.
	http://en.wikipedia.org/wiki/File:Electromagneticwave3D.gif	The animation you saw in the video lesson. You can open it and let it play for as long as you wish.
4. The Electromagnetic Spectrum	http://missionscience.nasa.gov/ems/05_radiowaves.html	A series of linked pages that deal with seven frequency ranges, radio waves to gamma rays.
5. The Energy of Electromagnetic Radiation	http://www.bbc.co.uk/schools/gcsebitesize/science/aqa_pre_2011/radiation/the_electromagnetic_spectrumrev1.shtml	Good detailed descriptions of the ways all the frequencies in the spectrum are used. Students can take a test at the end.

Task

Question 1

YFM broadcasts on 99.2 MHz. What is the wavelength of the broadcast? Answer to the nearest metre.

Hint: Use the wave equation: c = fλ.
Rearrange it to make wavelength the subject of the equation. To do this, divide both sides of the equation by f.

Question 2

In a commentary box at a stadium, a radio announcer is reporting on a soccer match in Maputo. A group of people in the room can hear his voice; they are 6 m away from him.

As he speaks, the information is carried on a radio wave to Cape Town, where it is heard by someone listening to a radio. Straight line distance to Cape Town from Maputo is 1 600 km.

Who hears the news first, the people in the commentary box or the person in Cape Town listening on a radio? Take the speed of sound in air as 330 m·s^{-1}.

Work your answers corrected to 3 decimal places

Question 3

A visitor goes to the technician in the transmitting radio station. The station is broadcasting at 3 000 kHz. The visitor asks how much quicker the signal will reach Cape Town if he increases the frequency to 6 000 kHz.

What do you think the technician will tell the visitor?

Question 4

Domestic microwave ovens heat food with electromagnetic radiation at 2 450 MHz.
The usual way to write large numbers in science is an integer, followed by a decimal point, followed by two decimal figures times a power of ten.
So express 2 450 MHz in this scientific notation. Your answer will be in the unit of gigahertz.

Question 5

What is the wavelength of the radiation inside a microwave oven? The wavelength needs to be shorter than the dimensions of the metal box where you place the food.

Question 6

Another microwave oven radiates with a wavelength of 100 mm. Work out the energy of a photon of the radiation inside the microwave oven.

Use the relationship, energy E = hf where h is Planck's constant and f is the frequency.

There are two ways to work this out.
First, you know that the wavelength is 100 millimetres, and you can work out the frequency f.
The other method is to work with just the symbols until you get an equation that has E, c, h

and lambda in it. Then you don't need to work out the frequency and you can use the wavelength that you are given.

Question 7

Electromagnetic waves travel through vacuum but they will also travel through some materials. Find some examples of such materials.

On the other hand, certain materials absorb the energy of electromagnetic waves and so the radiation does not pass through those materials.
Design an investigation to find out which materials will absorb and stop radiation of 900 MHz.

You can use your cell phone as a receiver, because 900 MHz is the frequency of cell phone signals in South Africa.

Question 8

The film Alien was a horror movie about the crew of a space station. A famous line from the film's advertising was "In Space, no one can hear you scream". What did the line mean? Would it always be true for the crew in the space station?

Task Answers

Question 1

3.024 m.

c = λf, and λ = $\frac{c}{f}$

Hertz means "the number of cycles per second" A number per second is just a number; it has no units, so we can write just "per second" or s^{-1}

c = $\frac{3 \times 10^8 \ m.s^{-1}}{99.2 \times 10^6 \ s^{-1}}$ = 3,024 m.

Question 2

Time for the sound wave to travel 6 metres:

Distance = speed x time,: t = $\frac{d}{v}$ = $\frac{6 \ m}{330 \ m.s^{-1}}$ = 0,018 s

Time for the radio wave to travel 1 600 000 m = $\frac{1 \ 600 \ 000 \ m}{300 \ 000 \ 000 \ m.s^{-1}}$ = 0,0053 s

The radio signal reaches Cape Town in less time than the sound travels in air across the room.

Question 3

Increasing the frequency will not increase the speed; the speed is never greater than the speed of light. However, increasing the frequency will change the wavelength, so the radio in Cape Town will lose the signal until somebody re-tunes it to 6 000 kHz.

Question 4

Manufacturers often give the frequency in terms of MHz.

1 MHz = 1 x 10^6 Hz, and 1 GHz = 1 x 10^9 Hz

2 450 MHz = 2 450 x 10^6 Hz = 2,450 x 10^9 GHz.

To get the answer, move the decimal three places to the left (divide by 1 000) while you increase the exponent by 3 (multiply by 1 000).

Question 5

From c = λf, we get $\frac{c}{f} = \frac{8f}{f}$ and so $\frac{c}{f} = 8$ and

$\frac{3 \times 10^8}{2,45 \times 10^9}$ $\frac{m.s-1}{s-1}$ = 1, 22 x 10^{-1} m = 0,122 m or 12, 2 cm.

This length is short enough to fit about 3 wavelengths inside the cavity of the microwave oven. This is important because the microwave sets up a standing wave inside the cavity.

Question 6

First method:

c = λ f, so f = $\frac{300 \ 000 \ 000 \ m.s^{-1}}{100 \times 10^{-3} \ m}$ = 3 x 10^9 = 3 000 MHz

Then E = hf, so E = 6.63 x 10^{-34} J. s x 3 x 10^9 s^{-1} = 19.89 x 10^{-25} J.

Second method, by first manipulating the equations:

f = $\frac{c}{\lambda}$, and substituting this relationship into E = hf, E = $\frac{hc}{\lambda}$

Then E = $\frac{6.63 \times 10^{-34} \times 3 \times 10^8}{100 \times 10^{-3}}$ J.s x m·s^{-1} x m^{-1}

= 19.89 x 10^{-25} J

Question 7

A simple way to test materials is to place a cell phone inside a container made of the material, such as cardboard, plastic, a suitcase, clothing, a drawer in wooden table, a glass jar, a tightly-closed glass jar under water, a metal biscuit tin. Use another phone to call the phone inside the box; if it rings, the signal from the local cell tower is penetrating the box's material.

The phone always rings except if it is enclosed inside a metal container, like a biscuit tin.

Try this further with a jam-tin, open at one end. Does it make a difference if the opening points in different directions? Find out where the nearest cell phone tower is, to know where the signal is coming from.

Question 8

There is no air in Space, so a scream would not propagate. Of course, if the crew had air inside the space station, then they could hear each other talk (and scream). Outside the station, they would have to use radios to talk to each other.

Acknowledgements

Credits

http://upload.wikimedia.org/wikipedia/commons/5/58/Man_speaking_on_mobile_phone.jpg
http://upload.wikimedia.org/wikipedia/commons/b/b8/Mug_of_Tea.JPG
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