Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

Electromagnetic radiation & 5G – myths and facts

science & technology in action
www.sta.ie
16th edition

What is 5G?

The term *5G* refers to the *fifth generation* of wireless technology which is currently being introduced in some cities and areas of higher population density in Ireland.

First generation devices, 1G, were limited to calls while the second, 2G, added text messaging or SMS (short message service). The third generation, 3G, allowed access to the internet and the current 4G allows faster data transfer with smoother internet browsing and video. 5G is the coming generation, and is forecast to have a revolutionary impact on business and society in general.

The underlying technology

All five generations of wireless technologies, and indeed all radio, TV and satellite communications, use frequencies in the radio and *microwave* sections of the electromagnetic spectrum.

The electromagnetic spectrum also includes visible light, infrared (i.e. heat radiation), ultraviolet and X-rays. What distinguishes them is their *frequency* and hence their *wavelength*; the higher the frequency, the shorter the wavelength. The diagram shows where they are located in the spectrum.

Some background

In 1665 the great British scientist Robert Hooke proposed that light was some kind of wave. In 1690 the Dutch mathematician-astronomer Christiaan Huygens proposed the first detailed wave theory of light. In 1675 and again in 1725 Isaac Newton proposed that light was composed of particles that had mass which varied with the colour. He explained the properties of light in terms of *gravitation*. Because of his reputation no one challenged his theory.

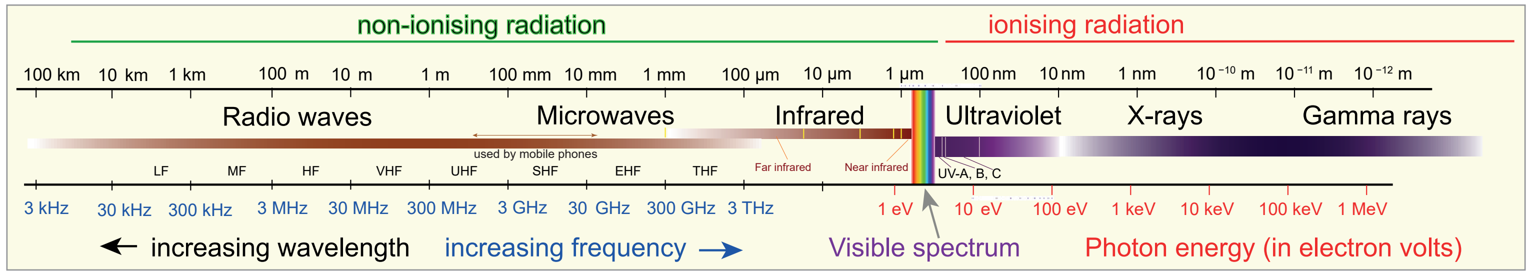
However, around 1800 Thomas Young showed conclusively that light behaves as a wave. But no one knew what was actually 'waving'. The particle theory was abandoned – for the moment. Around the same year invisible rays were discovered at either side of the visible spectrum; these were called infrared (i.e. below red; IR) and ultra violet (i.e. beyond violet; UV).

In 1845, after many failed experiments, Michael Faraday showed that polarised light was affected by a magnet. This very surprising result inspired James Maxwell to produce a complete *electromagnetic* theory of light which was eventually published in 1873. His theory anticipated the transmission of *radio waves*, first demonstrated in 1887 by Heinrich Hertz.

The realisation grew that these different kinds of radiation – light, IR, UV and radio waves, were all forms of electromagnetic radiation, just with different wavelengths. X-rays were discovered in 1895 and gamma rays in 1900.

Energy of electromagnetic waves

During the late 1800s many scientists studied what became known as the *photoelectric effect*. When an *electroscope* was charged negatively, it could be discharged by shining ultraviolet light on it but visible light had no effect. The puzzle was solved in 1905 by Albert Einstein. (It was for this he was awarded the Noble Prize in 1921 – not for his theory of relativity.) What Einstein proposed was that light and other electromagnetic waves also behaved as particles or



'*photons*' as he called them. This was a new particle theory of light, quite different from Newton's. According to Einstein, higher frequency radiation (= shorter wavelength) had higher energy. UV photons had enough energy to knock electrons off a negatively charged metal plate but red or green or blue light did not.

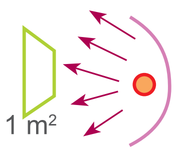
This important result is key to understanding the energy of all electromagnetic waves. The energy is **directly proportional to the frequency**: $E \propto f$. So, what does this mean?

The radio frequencies used by mobile phones are in the UHF and SHF bands with wavelengths ranging from 1 metre to 1 centimetre (see table above). These are all at least 10,000 times less energetic than visible light and so cannot cause *ionisation*, i.e. they cannot cause the formation of *ions*. Radio waves of all kinds, including microwaves (300 MHz – 300 GHz), as well as infrared all have longer wavelengths, and lower frequency, than visible light; they are all *non-ionising*. Visible light is also a non-ionising electromagnetic wave.

At the very high energy side of the spectrum we have *ionising radiation*: ultraviolet (UV-C), X-rays and gamma rays, with increasingly higher energies. They are dangerous because they can ionise molecules, including *bio-molecules*. Their energies are usually expressed in *electron-volts* (eV). UV-A & UV-B are non-ionising. Only UV-C is considered to have enough energy to ionise. However, most UV-C from the Sun is blocked by the *ionosphere*. Skin cancer is thought to be caused mainly by UV-B photo-electric effects.

Note: The definition of ionising radiation is somewhat arbitrary; the borderline is given variously as 10 eV, 14 eV and 33 eV; these are the ionisation energies for oxygen, hydrogen and water molecules respectively. However, *UV-B* photons have energies of about 4 eV and can definitely cause skin damage.

Effects of non-ionising radiation



If you sit in front of a fire your skin absorbs infrared radiation (what we call radiant heat) and you feel warmed by it. However, if you go too close your skin may become burned; your blood cannot remove the heat fast enough and your skin gets toasted.

Infrared and microwaves are commonly used to cook food. Ovens, grills and toasters use infrared radiation (with wavelengths ranging from about 6 to 2 *µm*, i.e. 0.006 to 0.002 mm). The 12 cm waves used by microwave ovens (at 2.45 GHz) have to travel further through the food before they are absorbed so they don't produce the surface 'browning' (mild burning) that grills and ovens do.

Hot things emit infrared radiation. In fact, everything in the universe emits electromagnetic radiation whose wavelength depends on its temperature. At 15°C our environment radiates about 390 W m^{-2} of infrared radiation with a peak wavelength of about 10 µm.

Microwaves and mobile phones

Mobile phones operate in the microwave part of the spectrum. The total power of a mobile phone tower with, for example, 15 antennas would be about 2 kW. If it radiates in all directions, then 10 metres away the radiation would be 1.6 W m^{-2} and at 100 metres it would be 0.016 W m^{-2}. [$2000/(4\pi r^2)$]. This is small compared to the IR radiation from the ground and surroundings (~ 400 W m^{-2}).

How does the *photon energy* compare? If the mobile mast transmits at 26 *GHz* its wavelength is 11.5 mm. However, the IR radiation from the environment peaks at about 10 µm (= 0.01 mm). So, IR photons have over 1,000 times more energy than the 26 GHz microwaves. At ground level the radiation from a mobile mast is insignificant in both quantity and photon energy compared to the IR radiation from the environment. [Using $c = f\lambda$, $\lambda = (3\times10^8)\div(2.4\times10^9) = 1.25\times10^{-1}$ m = 12.5 cm]

WiFi and Bluetooth

WiFi, which is used for local wireless communications, operates on 2.4 GHz and 5 GHz bands with a maximum power of just 1 W, limiting its range. Bluetooth, which is based on WiFi, also uses the 2.4 GHz band at a maximum power of 0.1 W, which is lower than the power of a mobile phone (0.4 W). These frequencies are all non-ionising.

What about 5G transmitters?

Fifth Generation (5G) services allow higher data rates – possibly ten times that of 4G but not all phones are capable of using it. In Ireland 5G will be provided on 700 *MHz*, 3.6 GHz and 26 GHz bands.

Two disadvantages of 26 GHz and higher frequencies is that they are more easily absorbed by obstacles and they diffract very little around corners. For best results they require line-of-sight between communicating devices. So, the widespread use of 5G phones in built-up areas will require a higher density of transmitters, probably one on every street, but smaller and of lower power than current mobile phone masts.

Should we be concerned?

There are some issues that should concern us as informed citizens.

1. Electromagnetic fields at very high intensities can be harmful. For this reason, there are strict EU regulations limiting exposure to EMF to ensure that people are not exposed to levels that might be harmful.
2. The amount of misinformation and myths in circulation, which raise concerns without providing real evidence.
3. Will future telecommunications, *Internet of Things* and working from home all require more electrical power, not just for antennas but more significantly for larger *data centres* to store the ever increasing amount of data?

The **Environmental Protection Agency (EPA)** is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

Regulation: EPA implements effective regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.

Knowledge: EPA provides high quality, targeted and timely environmental data, information and assessment to inform decision making at all levels.

Advocacy: EPA works with others to advocate for a clean, productive and well protected environment and for sustainable environmental behaviour.

Responsibilities

- Licensing of activities so that they do not endanger human health or harm the environment (e.g. waste facilities, large scale manufacturing, power plants, intensive agriculture, ionising radiation)
- Conducting inspection and enforcing regulations (e.g. public supplies of drinking water, waste management).
- Water management (e.g. monitoring and reporting on the quality of rivers, lakes, bathing water, etc.)
- Monitoring, analysing and reporting on the environment (monitoring air quality, implementing relevant EU directives)
- Regulating Ireland's greenhouse gas emissions
- Regulating ozone-depleting substances
- Environmental research and development
- Strategic environmental assessment (e.g. assessing the impact of proposed major developments).
- Radiation protection (ionising and non-ionising)
- Guidance, accessible information and education
- Awareness raising and behavioural change (e.g. influencing positive behavioural change relating to the environment, promoting radon testing in homes and workplaces)

For more information from EPA on electromagnetic fields go to: http://www.epa.ie/radiation/emf/

You can find out more about the work of **EPA** at www.epa.ie

Find this and other lessons on www.sta.ie

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Syllabus References

The main syllabus references for the lesson are:

Leaving Certificate Physics

- Waves: Relationship $c = f\lambda$. Reflection, refraction, diffraction, interference, polarisation. (p. 12)
- Electromagnetic spectrum: Relative positions of radiations in terms of wavelength and frequency. (p. 15)
- Electromagnetic Induction: Magnetic flux, $\Phi = BA$; Faraday's law. Lenz's law. (p. 19)
- Properties of X-rays: electromagnetic waves, ionisation, penetration. (p. 20)

Leaving Certificate Technology

- Information and Communications Technology (p. 30)

Leaving Certificate Politics and Society

- The ability to constructively engage in debate as a means of coming to reflective and informed positions is a central skill for democratic participation. (p. 15)
- Students should be able to describe the process of decision-making at national level in relation to a policy that impacts upon young people. (p. 24)

Leaving Certificate Geography

- The effectiveness of urban planning strategies and urban renewal in solving urban problems (p. 29)

Science and Technology in Action is also widely used by **Transition Year** classes.

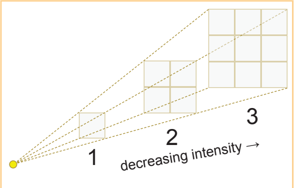
Learning Outcomes

On completion of this lesson, students should be able to:

- Explain how the understanding of the electromagnetic spectrum developed
- Distinguish between the different kinds of electromagnetic radiation in terms of wavelength, frequency and energy
- Describe the evolution of mobile communications technology and the advances in each generation
- Explain the significance of the photoelectric effect and how it relates to electromagnetic waves
- Compare the energy of photons of different kinds of electromagnetic radiation
- Distinguish between ionising and non-ionising radiation
- Outline how electromagnetic radiation decreases with distance from the source and discuss the radiation from mobile phones and other microwave sources, in the context of solar radiation and environmental infrared radiation
- Discuss possible concerns in relation to communications technology, particularly 5G.

Student Activities

1. Find out what is meant by the following acronyms: LF, MF, HF, VHF, UHF and SHF in the diagram on page 1.
2. Explain why light is referred to as electromagnetic? What is the essential difference between the various forms of electromagnetic radiation.
3. The radio station 2FM transmits on 90 MHz – 92 MHz. Show that the wavelength of the transmission is about 3.3 metres. ($c = f\lambda$, where $c = 3{\times}10^8$ m s^{-1})
4. The energy of a photon in joules is given by: $E = hf$, where f is its frequency and h is Planck's constant, 6.626×10^{-34} J s. Calculate the energy of a photon of each of the following: 90 MHz, 30 GHz, 3 mm radio wave, 0.1 mm IR, orange light (600 nm) and violet light (700 nm). ($E = hf$ or $E = hc{\div}\lambda$)
5. Caesium is the element with the lowest ionisation potential, 3.9 eV. This is UV light with $\lambda = 318$ nm. So, all longer EM waves cannot cause ionisation. Find out how certain molecules in the photoreceptor cells of the eye can detect single photons with lower energies than this but are not ionised. (Look up 'rhodopsin'.)
6. Radiation from a candle or an electric light spreads out in all directions through successively larger surface areas. Explain why the illumination is proportional to $1/r^2$ where r is the distance from the source.



True/False Questions

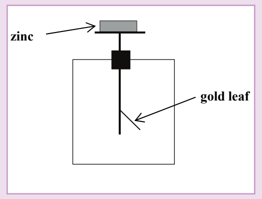
a) Each generation of mobile phones was faster than the previous one.	T F
b) Mobile phone signals are sound waves.	T F
c) Higher frequency waves have shorter wavelengths.	T F
d) Huygens devised the electromagnetic theory of light.	T F
e) The energy of photons is proportional to their wavelength.	T F
f) All electromagnetic radiation is non-ionising.	T F
g) The energy of ionising radiation is usually expressed in electron-volts (eV).	T F
h) 26 GHz radio waves have longer wavelength and lower energy than visible light.	T F
i) Only a small fraction of the electromagnetic radiation we receive is man-made; most of it is natural.	T F
j) Blackbody radiation refers to the electromagnetic radiation emitted by everything in the universe.	T F
k) 26 GHz radio waves are easily absorbed by walls etc.	T F

Check your answers to these questions on www.sta.ie.

Examination Questions

Leaving Certificate Physics 2006 (OL) Q. 12

In an experiment to demonstrate the photoelectric effect, a piece of zinc is placed on a gold leaf electroscope, as shown. The zinc is given a negative charge causing the gold leaf to deflect.



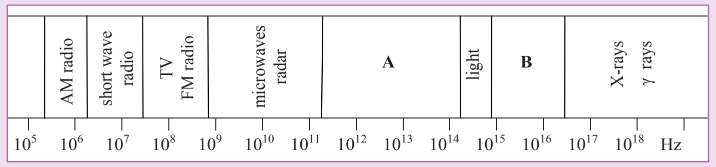
- Explain why the gold leaf deflects when the zinc is given a negative charge.
- Ultraviolet radiation is then shone on the charged zinc and the gold leaf falls. Explain why.
- What is observed when the experiment is repeated using infrared radiation?

Leaving Certificate Technology 2014 B (HL) Q. 3 b iii

Differentiate between infrared and radio frequency in relation to wireless transmission.

Leaving Certificate Physics 2012 (HL) Q. 7

The diagram shows a simplified version of the electromagnetic spectrum.



- Name the sections labelled A and B in the diagram. Describe how to detect each of these radiations.
- An electromagnetic radiation has a wavelength of 4 m. Name the section of the electromagnetic spectrum in which this radiation is located.

Leaving Certificate Technology 2009, (OL) B: ~Q. 5d

- Calculate the wavelength of a radio wave whose frequency is 26 GHz. ($c = f\lambda$, $c = 3.0 \times 10^8$ m s^{-1})

Leaving Certificate Technology 2010 (HL) Q. 11 g

- A mobile phone transmits at 1200 MHz from its antenna. Calculate the length of its antenna, which is one quarter of the wavelength that it transmits.

Leaving Certificate Technology 2004 (HL) Q. 10 iv, v

- Name a detector of ionising radiation.
- Outline the principle on which the detector works.

Great care has to be taken when dealing with radioactive sources.

Give:

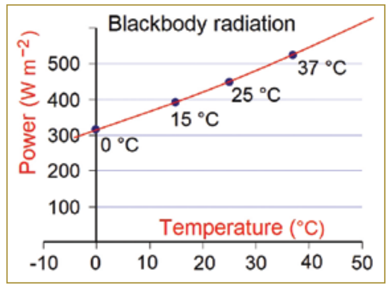
(i) two precautions that should be taken when dealing with radioactive sources;
(ii) one use of a radioactive source;
(iii) one harmful effect of ionising radiation.

Did You Know?

Human radiators!

The human body radiates infrared, with a peak wavelength of about 9 μm; this radiation enables infrared cameras to 'see' people (and animals) in the dark. Our clothes prevent us from losing too much heat but on average we still radiate at roughly 100 watts, that is 100 joules per second. (This is actually the difference between what we radiate to the environment and what the environment radiates back to us.)

Our surface temperature (including clothes) is about 28°C so the IR radiation is about 470 W m^{-2}. (See graph.) The radiation from the environment at 15°C is near 400 W m^{-2}. The average human body surface area is 1.5 to 2 m^2.



Historical Notes

Five generations of mobile phones

The 1st generation (1G) cellular mobile phone networks appeared in 1981. They used analogue voice signals which could be intercepted by using suitable radio receivers.

The 2nd generation (2G) was introduced in 1991. Voice calls were digitised and encrypted. They also introduced text messaging (SMS) and useful apps.

By 2001 3G networks were developed to provide higher data rates for internet and multimedia services, including streaming video.

The 4th generation (4G) was introduced in 2009. 4G networks have higher data speeds – 5 to 10 times faster than 3G – and support high definition (HD) video streaming.

5G, introduced in 2018, provides even higher data rates.

Revise The Terms

Check the meaning of the following key terms:

5G, bio-molecule, blackbody radiation, data centre, electromagnetic, electron-volt, electroscope, fifth generation, frequency, GHz, gravitation, Internet of Things, ionisation, ion, ionosphere, kW, MHz, microwave, photoelectric effect, photon, photon energy, radio waves, wavelength.

Check the Glossary of terms for this lesson on www.sta.ie