Name: ______________________________________ Class: _________ Date: ___________

Sec 3 Physics

Worksheet 4: EM waves

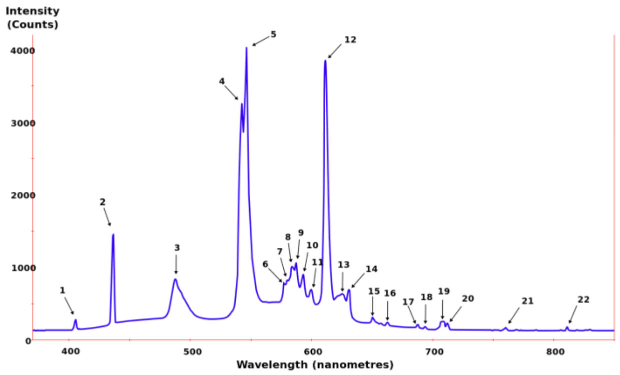
Conceptual Questions

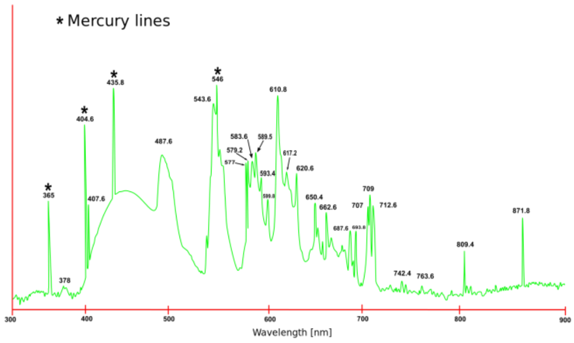
1. What colour of the visible spectrum has the longest wavelength? Which has the shortest wavelength?

   Red has the longest wavelength, and violet the shortest.

2. In a boutique store with only fluorescent lighting, a customer insists on taking dresses into the daylight at the doorway to check their colour. Is she reasonable? Explain.

   Yes. The profile (or distribution) of wavelengths are quite different. Take a look at the distribution of light given out by a standard fluorescent light (left) and a natural sunshine fluorescent (right). We can see the absence of several wavelengths. For example, in the normal florescent, a piece of navy-blue clothing can easily be mistaken as black.





Spectrum from a 48" Philips F32T8 natural sunshine fluorescent light

3. Fire engines used to be red. Yellow-green is now the preferred colour. Why?

   Under broad daylight, the difference is small. However, in the darkness of night, red is not so easily seen by the eye. Our eye is most sensitive to yellow-green colour, which is the dominant wavelength that the Sun produces. Therefore, painting fire engines yellow-green make them more easily distinguishable at night.

   (Singapore has yet to adopt this new colour scheme)

4. Which EM waves are associated with high-energies? Which ones are the low-energies?

Short wavelengths, such as gamma rays, X-rays and UV, are considered as high energy.

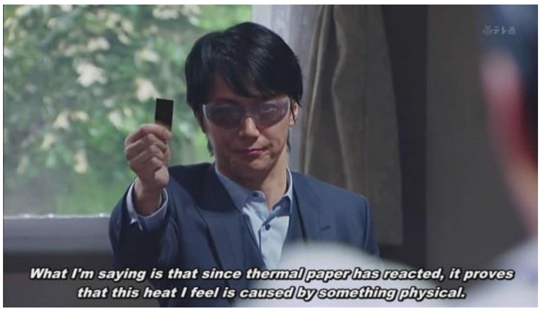
Radio waves, microwaves and infrared are considered as low energy.

5. Does a microwave photon have a lot of energy? How can our food be "cooked" by microwaves?

The complete description of the workings of a microwave oven is beyond the scope of the syllabus. However, while a single photon of microwave does not have a lot of energy, we can still get a lot of microwave energy if we concentrate a lot of microwave energy at a particular location. This high output of microwave energy is what the microwave oven does. A typical microwave oven uses about 1000 W during its operation. (1 W is 1 J of energy per second)

6. Can radar cook birds which happen to fly by during its operation?

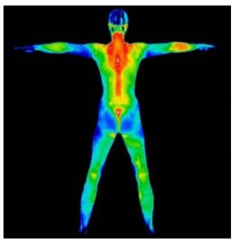
There are often allegations that an intense pulse of radar (radio waves) can cook unfortunate birds that fly past the radio dish. To check this claim, *Mythbusters* used a microwave transmitter to show that a cold turkey cannot be heated up significantly by merely putting it in front of a radiating dish. https://www.youtube.com/watch?v=-czRE9rdHMA&hl=en-GB&gl=SG. However, in the televised Japanese drama series *Galileo 2*, the physicist (actor) showed an intense microwave beam directed at him that could burn a train ticket (thermal paper). The question about the birds cooked by radar remains an open one.



In the show Galileo Season 2 episode 1, Professor Yukawa showed that a beam of intense microwave directed at a person can cause harm. He wore a special eyewear to protect his eyes from the microwaves.

7. Human beings have a body temperature of around 37^{o}C. What is the dominant EM radiation that our bodies emit?

The dominant wavelength produced by the human body is mostly in the infrared. That is why infrared thermometers are used to measure body temperatures. (Right): Infrared imaging. The hotter parts are shown as red, and the cooler parts are blue.



8. Can the human body produce EM waves other than infrared?

Yes. However, it is very, very little in quantity compared to infrared. The larger the energy difference between that radiation and infrared, the lesser the radiation's quantity.

However, we can do things to enhance other forms of radiation in the human body. For example, in a **positron emission tomography (PET)** scan, a radioactive isotope is injected into the body to induce gamma rays' emission.


A PET/CT scan system

9. Does light travel infinitely fast, or does it have a finite speed?

The speed of light (or EM waves) is finite and is 299 792 458 m s^{-1}. In practice, we say it is 3.00×10^{8} m s^{-1}. According to the theory of relativity, nothing travels faster than light in a vacuum.

10. Can we look into the past?

We are always looking into the past. Since light takes time to travel from the object to our eyes, the light emitted from an object must have been emitted some time ago. The light from the person next to you was emitted a nanosecond earlier. The light from the Sun was emitted 8.5 minutes ago. The light from the nearest star was emitted more than four years ago, and the farthest objects in the Universe emitted their rays 13 billion years ago. Very ancient light indeed.

11. Is Earth a bright object in the solar system?

That depends on which part of the EM spectrum. Since the 1950s, there has been increasing use of radio waves on Earth (for telecommunication). Earth is, therefore, quite bright in radio. There are distinct differences between the radio from the Sun. For example, the Sun emits radio in a continuous spectrum while Earth's radio is emitted at specific frequencies. Do we have to be wary about aliens noticing our radio waves? The human-made radio waves that Earth emitted have reached about 70 light-years, so we do not have to worry that some extra-terrestrials will soon visit us.

12. There is a rule (Wien's displacement law) that tells us the type of radiation an object emits depends on its temperature. Cool objects emit radio waves mostly, while very hot objects (e.g. plasma of about 10 million K) emit X-rays primarily. Therefore, by looking at the colour of stars, we can tell how hot the star surfaces are. There are red stars, orange stars, yellow stars, blue stars and white stars. Why are there no green stars?

In the visible light spectrum, green is somewhere in the middle, sandwiched between blue and yellow. In other words, if a star is emitting in green dominantly, it is also emitting significant amounts of blue and yellow. The combination of the various wavelengths makes the star appear white.

SECTION A: MULTIPLE CHOICE QUESTIONS

1 B	2 C	3 A	4 C	5 D	6 D	7 C	8 C	9 B	10 B	11 D
12 A	13 C	14 A	15 B							

SECTION B: STRUCTURED QUESTIONS

1 Complete the gaps in the diagram of the electromagnetic spectrum. [1]

RADIOWAVES	Microwave Infrared	Visible light	Ultra-violet	X-rays	GAMMA

b) State two properties of ultra-violet radiation, which differ from those of infra-red radiation.

UV radiation has a higher frequency and can cause more harm to live tissues and organisms.

c) State two properties that are common to all forms of electromagnetic radiation.

Any two appropriate properties

1. They are all transverse waves.
2. They travel at a 3.0×10^{8} m s^{-1} in a vacuum but slow down in other media.
3. They do not require any material medium to spread from one point to another.
4. They transfer energy from one place to another.
5. They obey the laws of refraction and reflection.

2 Very short-wavelength radio waves can be used to determine the Moon's distance from the Earth by measuring the time taken for radio waves to travel from the Earth to the Moon and back again.

Calculate the delay between the transmission and reception of the signal when the Moon is 3.9×10^{8} m from the Earth, given that the speed of electromagnetic waves is 3.0×10^{8} m s^{-1} .

$$t=2\left(\frac{d}{v}\right)=2\left(\frac{3.9\times10^{8}}{3.0\times10^{8}}\right)=2.6\text{ s}$$

3a) Red on top, violet below

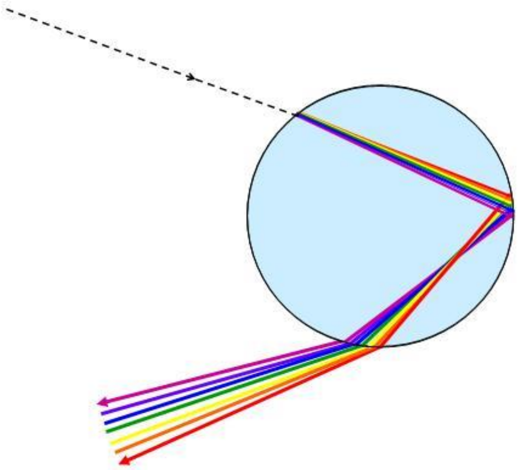
b) Refractive index of violet is more than 1.5. The refractive index is inversely proportional to speed which is directly proportional to wavelength. Violet has a shorter wavelength and hence a larger refractive index.

c) UV is beyond violet.

d) Photographic plates

e) Greater

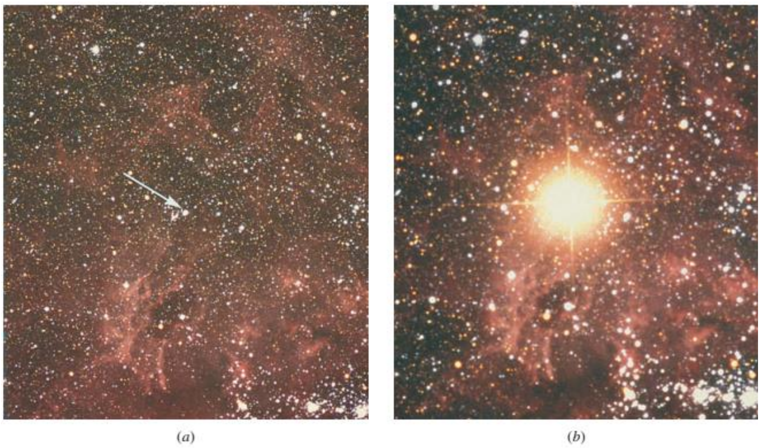
4 a)



4b)

Blue light has a shorter wavelength than red light. Hence, the blue light's speed in water is slower than that of red light, meaning it has a smaller refractive index. It will have a smaller angle of refraction upon entering the droplet. After total internal reflection in the droplet, it will incident on the glass-air surface with a smaller incidence angle, resulting in a small angle of refraction in air.

5 **Far Light is Old Light.** A supernova is an explosion that occurs at the death of certain stars. For a few days after the supernova, the emitted light's intensity can become a billion times greater than that of our own Sun. After several years, however, the intensity returns to zero. Supernovae are rare events in the Universe; only six have been observed in our galaxy within the past 400 years. A supernova that occurs in a neighbouring galaxy approximately 1.66×10^{21} m away was recorded in 1987.



(a) Before the supernova (b) After the supernova

(a) How many years before 1987 did the supernova occur at the neighbouring galaxy? [2]

$$t = \frac{d}{c} = \frac{1.66 \times 10^{21}}{3.00 \times 10^{8}} = 5.53 \times 10^{12} \text{ s } = 175000 \text{ years}$$

(b) Astronomers often say that the further the event is from Earth, the further in time we see. Can you elaborate on this statement?

- Light takes time to travel. E.g. the supernova was 175000 light-years away
- We are looking at the event as it was 175000 years ago (and not its present state).

[2]

** **(c)** The earliest moment in time is the Big Bang itself. If we look far enough, can we see the Big Bang $(t = 0)$? Justify your answer.

There is nothing wrong with the reasoning about looking far enough. The only problem is light from the earliest moment of the Universe did not exist anymore. The early Universe was very hot, and matter existed in the state of *plasma*. In this state, matter was opaque to light. The earliest photons were absorbed and re-emitted by this plasma state. No photons from the moment of the Big Bang survived till today.

** **(d)** If we cannot see the Big Bang, how far into the past can we see?

Carrying on the description in (c), the Universe continued to cool down as time passed. The plasma particles slowed down as the Universe cooled. At about 400 000 years after the Big Bang, the Universe finally cooled sufficiently for the electrons and protons to merge to form hydrogen atoms. Unlike the earlier plasma, hydrogen was transparent, and light could stream across the Universe unhindered, and the Universe lighted up. This event was so momentous that scientists named it the *Age of Recombination*.

The light from this recombination age is still around today. We called it the Cosmic Microwave Background Radiation. It was first predicted by Ralph Alpher and Robert Herman in 1948 and discovered by Penzias and Wilson in 1964. Penzias and Wilson were awarded the Nobel Prize for this discovery.

Because the Universe at that time was homogeneous and isotropic, the Universe turned transparent at every location at the same time. The newly formed hydrogen gas's temperature was about 3000 K, and as such, it was glowing red. As time passed, the hydrogen continued to cool. Eventually, the temperature dropped to the extent that the hydrogen was no longer emitting red light but infra-red, and the Universe turned dark again. The Universe remained dark until some hydrogen clouds condensed sufficiently to form the first stars, which re-lighted the Universe.

6

Global Position System (GPS) satellites transmit radio signals used by receivers on the Earth to determine position with very high precision. The operating principle is that a receiver gets signals simultaneously from several different satellites (typically at least four) and uses them to "triangulate" its position. This method relies on precise knowledge of the time it takes for a satellite signal to reach the receiving position. Until a few years ago, the US government intentionally degraded the timing information so that it had an uncertainty of about 350 ns. Based on the timing error, estimate the precision in metres to which the position can be determined.

Use $c = 2.9979 \times 10^8$ m s^{-1}

$$\text{distance} = \textit{speed} \times \textit{time}$$
$$= \left(2.9979 \times 10^8\right) \times \left(350 \times 10^{-9}\right)$$
$$= 105 \text{ m}$$