

3. THE ELECTROMAGNETIC SPECTRUM

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3.1 Electromagnetic spectrum explorer

Instructions on use

Open the *Electromagnetic spectrum explorer* learning object and hit the **Start** button located at the bottom right.

To navigate through the spectrum, click and drag the slider along the spectrum bar. When scrolling information on the band, wavelength, frequency, photon energy and other general information will be displayed in the windows at the bottom of the screen.

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3.2 Investigating the electromagnetic spectrum

Electromagnetic spectrum explorer learning object exercises

This section will allow the students to use the interactive *Electromagnetic spectrum explorer* to investigate the relationships between the velocity, wavelength, frequency, and energy of electromagnetic radiation. This section consists of an introductory exercise followed by two tasks.

Please note:

- When students select data from the *Electromagnetic spectrum explorer* ensure they only select data from small range of the spectrum (for example select values within the same power of 10).
- DO NOT attempt to get students to graph manually. Feedback received from trial schools has stated that this is too difficult for students.
- It may assist your students to review measurements and SI units. Some common measurements are listed below.

Quantity	Unit	Symbol	Symbol of compound unit
mass	kilogram	kg	-
length	metre	m	-
time	second	s	-
velocity	metre per second	m s^{-1}	-
force	Newton	N	kg m s^{-2}

The Western Australian formula and constants sheet for physics can be found at http://www.curriculum.wa.edu.au/pages/syllabus_manuals/volumes/VII_science/physics.htm

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3.3 Investigating the electromagnetic spectrum

1. What do you understand by the following **quantities and their units**?

Wavelength (λ)

Unit:

Frequency (f)

Unit:

Velocity (v)

Unit:

2. Multiply the wavelength units by the frequency units and state what quantity the resulting units represent.
3. Write a formula that shows the relationship between all three quantities.

Well done, you have now established the validity of a science formula by unit analysis.

Task 1 – To find the speed of light

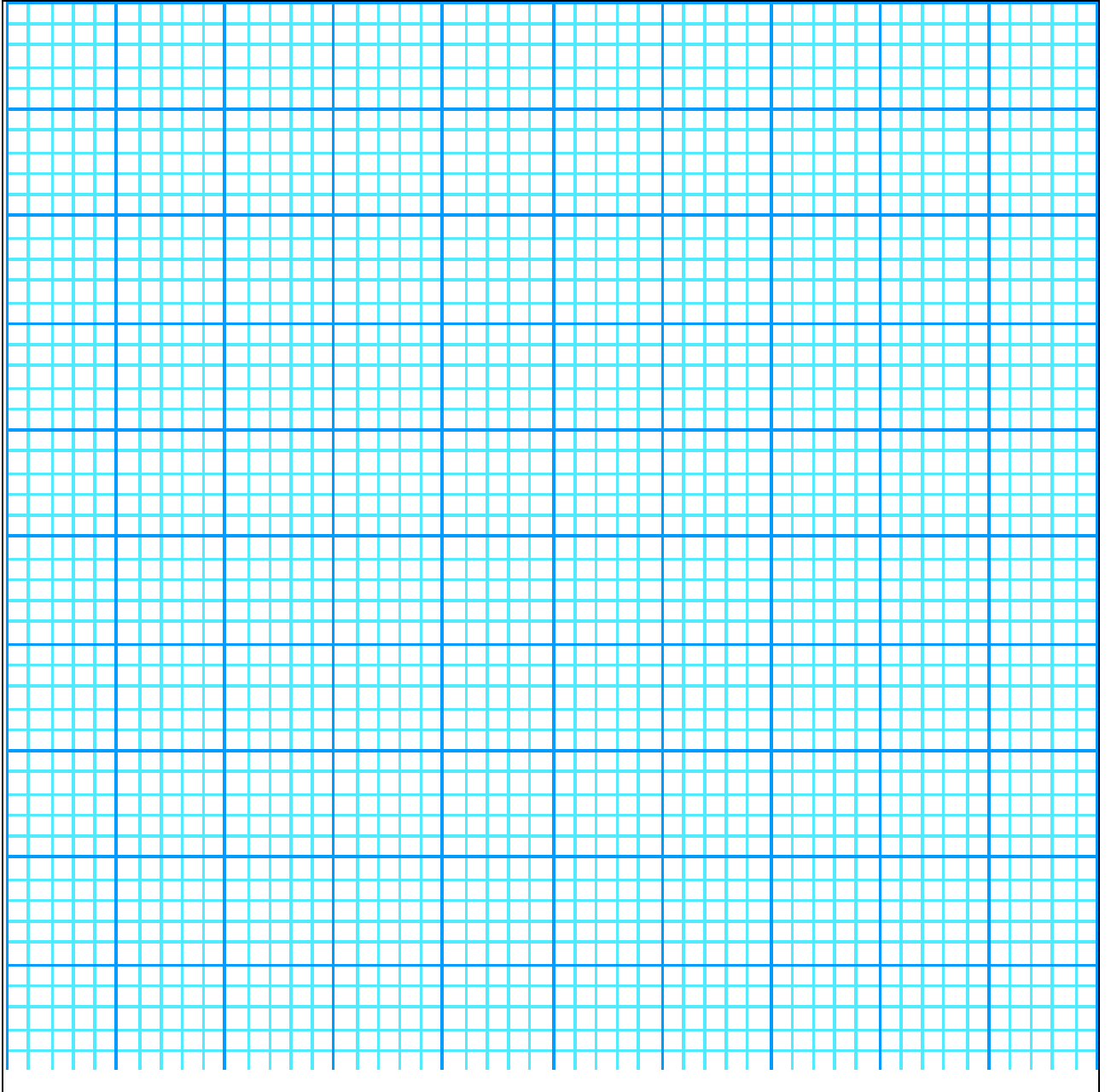
Einstein established that the speed of light (c) is a constant value in a vacuum.

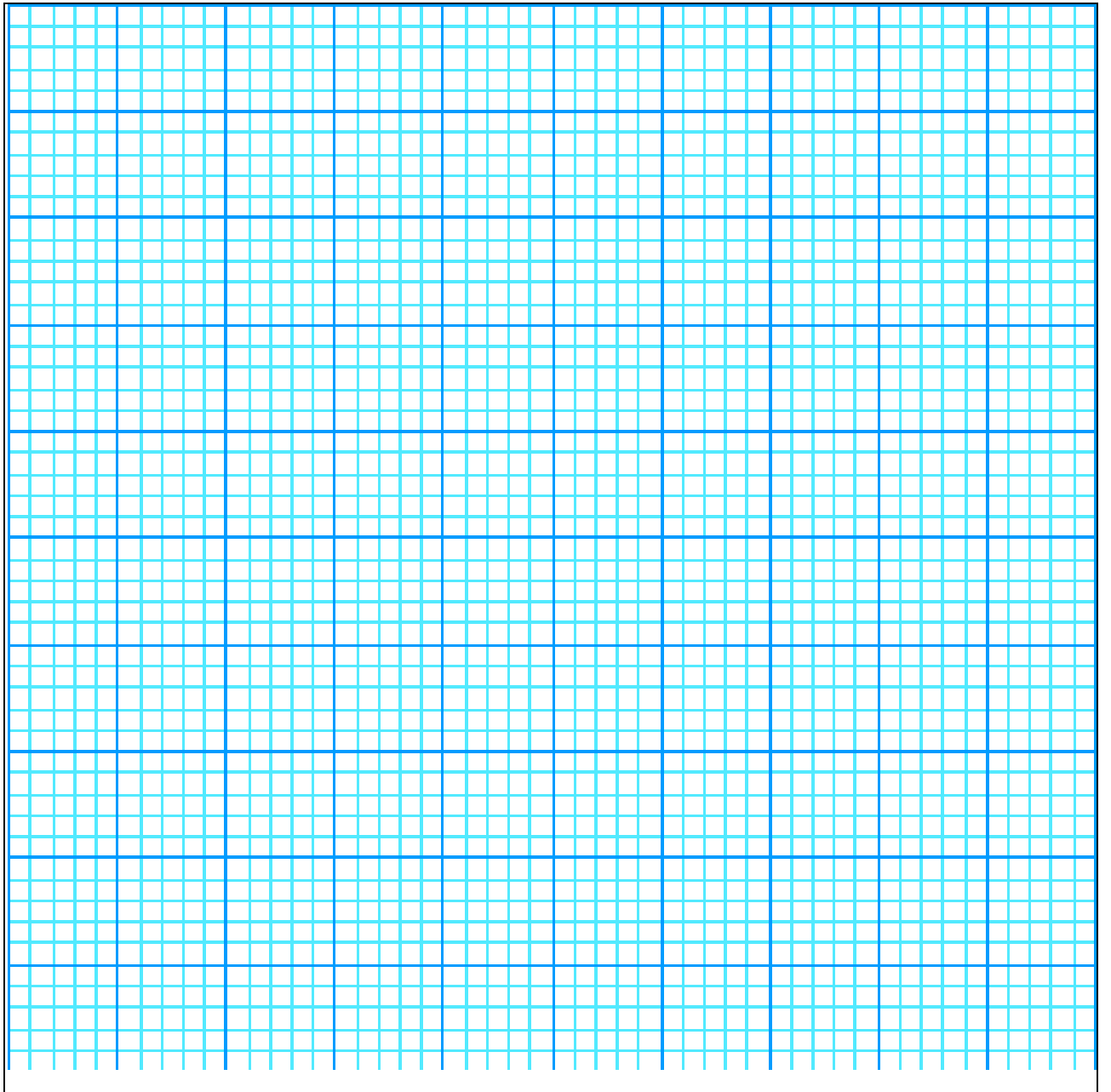
Using the *Electromagnetic spectrum explorer* and the relationship you established in the last activity, analyse data to find the speed of light.

Method

1. Open the *Electromagnetic spectrum explorer*.
2. Using the slide select 10 pairs of values for wavelength and frequency using a small data range, eg keep all frequencies within the same power of 10.
3. Record this information in the table below.
4. Plot two graphs:
 - a. frequency vs. wavelength,
 - b. frequency vs. the inverse of wavelength.

	Frequency (Hz)	Wavelength (m)	$\frac{1}{\text{Wavelength}}$ (m^{-1})
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			





Exploring your graphs and making some deductions

1. Which graph gives a straight line?
2. What does this imply about the relationship between the wavelength and the frequency in terms of proportionality?
3. Write a formula for the relationship stated above.
4. What do you think the slope of the straight line graph represents? Please give units.

This method of analysis is common in science. Finding a mathematical relationship between variables is very important to accurately predict what will happen if you change one of those variables.

Test your understanding, by answering the following questions. The relationship between velocity, constant acceleration and time are shown below.

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

$$\text{acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time taken}}$$

or

$$a = \frac{v - u}{t_v - t_u} \text{ m s}^{-2}$$

In Year 11 you may see this written as $a = \frac{\Delta v}{\Delta t} \text{ m s}^{-2}$ where Δv is change in velocity and Δt is change in time.

5. What is the constant in this formula?

6. What are the dependent and independent variables in the formula?

7. Which two variables would you have to plot to get a straight line graph?

8. What does the slope of the graph represent?

Task 2 – Exploring the relationship between frequency and energy of electromagnetic radiation

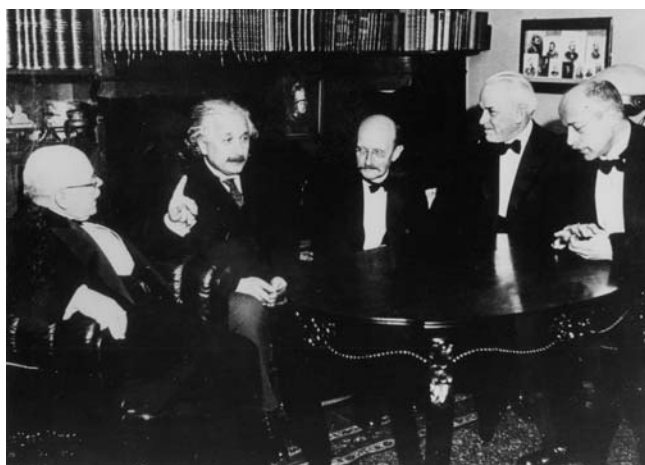
In 1900, Max Planck (1918 winner of a Nobel Prize in Physics) proposed a theory explaining how energy is absorbed and liberated by matter. At that time, people thought that energy flowed on a continuous basis in and out of matter.

For example, by standing in the sun you warm up. This is because your body has absorbed EMR and your matter interacts with this EMR causing it to vibrate more rapidly. As the frequency of the EMR waves increases it can do more and more damage to us if we are exposed to it.

Planck proposed that at the atomic level, energy is absorbed or liberated in packets or chunks of energy. Planck called these packages of energy ‘quanta’. In 1902 Philipp Lenard (1905 winner of a Nobel Prize in Physics) described measurements of electrical current flow from surfaces in a vacuum when exposed to light – the Photoelectric Effect. The experimental results were very surprising and could not be described using the then current concepts in Physics.

A young man who worked as a technical assistant in the Swiss Patent Office heard about the work of Planck and Lenard. In 1905 he proposed a new concept in Physics, related to Planck’s ideas and describing the results of Lenard’s photoelectric experiment. His name was Albert Einstein (1921 winner of a Nobel Prize in Physics).

These scientists were performing typical basic research that sought no immediate application, but extended the knowledge base of human kind.



Albert Einstein and Max Planck (second and third from the left) sitting next to each other with fellow Nobel Prize winners in 1928.

Image courtesy: Physikalisch – Technische Bundesanstalt, courtesy AIP Emilio Sagrè Visual Archives, Born Collection

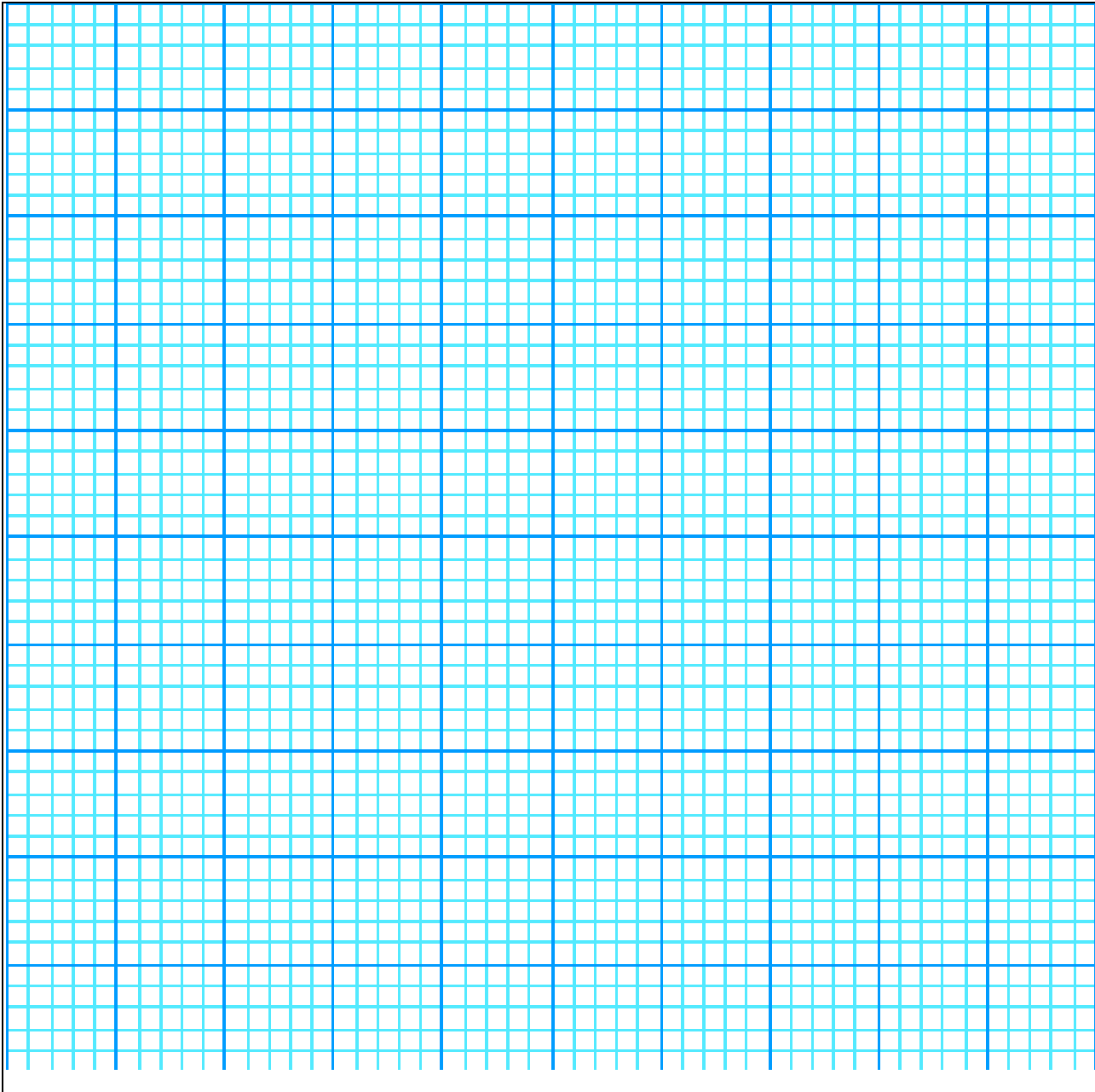
This story of three research scientists exploring the world through experiment and concepts is a great example of the importance of ‘basic research’ as contrasted with ‘applied research’. Basic research is experimental and conceptual activity for the sole purpose of extending human knowledge. Very little, if any, application or immediate usefulness is intended from such research – it is aimed at describing the world around us. It is from these initial steps that many years later applications of huge importance may flow.

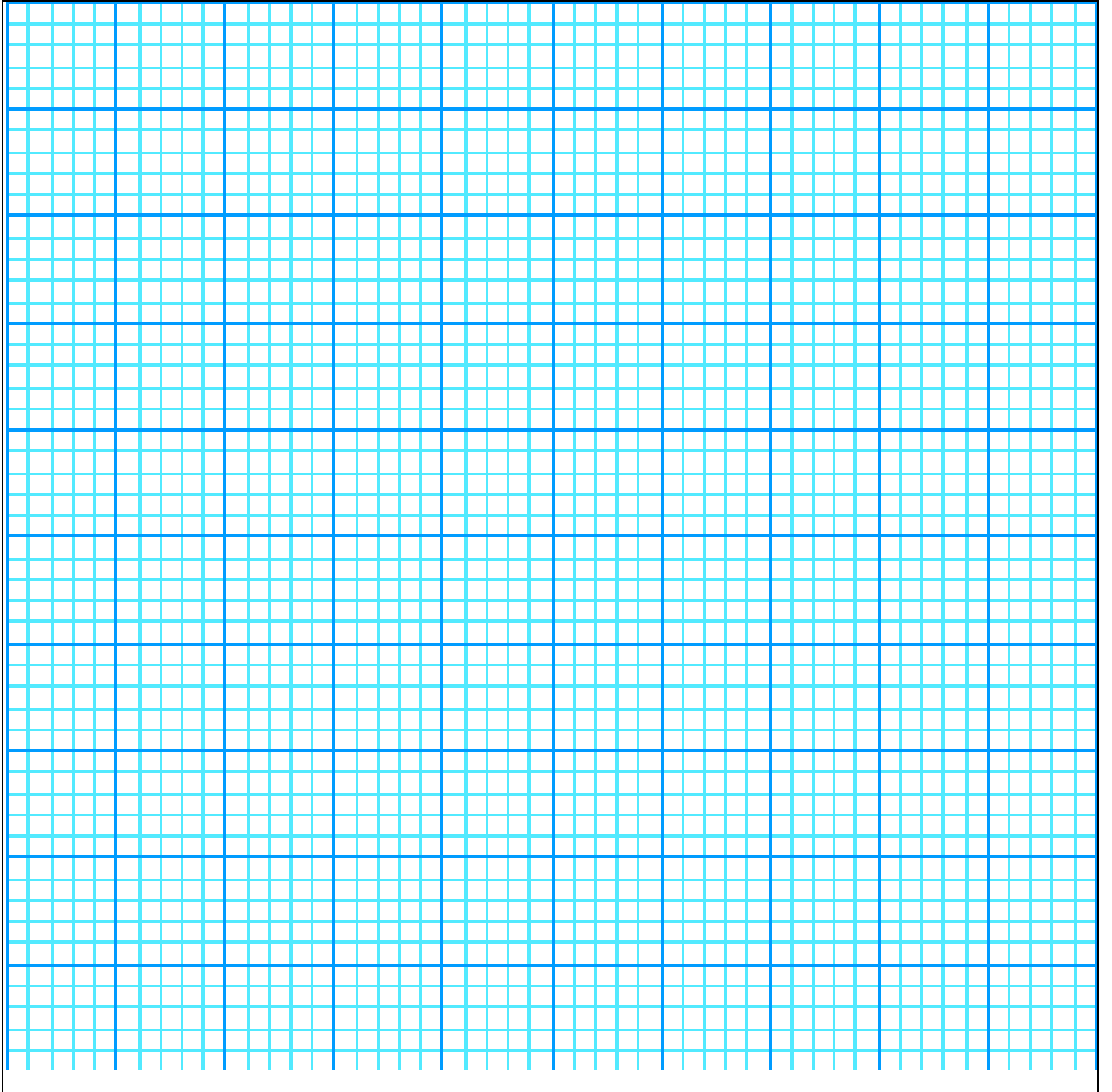
- Using your own knowledge and the information sheet '3.4 Interaction with Matter' complete the table below.

Type of electromagnetic radiation	Penetrating power	Damage
radio		
microwave		
infrared		
visible		
ultra violet		
X-rays		
gamma rays		

- Open the *Electromagnetic spectrum explorer*.
- Using the slide select 10 pairs of values for wavelength, energy and frequency. Use a small data range.
- Record these in the table provided.
- Using this information, plot two graphs:
 - frequency vs. energy
 - wavelength vs. energy

	Frequency (Hz)	Energy (J)	Wavelength (m)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			





Exploring your graphs and making some deductions

1. Which graph gives a straight line and which does not?
2. What does this imply about the relationship between the wavelength and energy, and frequency and energy in terms of proportionality?

To make proportionality an equality, there is a constant that makes it always true.

For example if: $A \propto B$ then $A = hB$ where h is a constant.

3. What is the value of the slope of the straight line graph (include units)?
4. Write a formula for the relationship between frequency and energy including the constant.

The constant is called **Planck's Constant** and has a value of $6.626068 \times 10^{-34} \text{ m}^2 \text{ kg s}^{-1}$.

5. Calculate the percentage error of your result.

This method of finding the **linear relationship** between variables by **experimentation** then finding the **physical constant** that creates the actual relationship is fundamental scientific method.

Hence Einstein's discovery is stated as: $E = hf$

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3.4 Interaction with matter

The interaction of EMR with matter

Synchrotrons provide immensely intense EMR which is used to investigate or construct structures. The way radiation interacts with matter provides researchers with crucial information used to carry out their studies and develop understanding of how things are made and how they function.

The following information will help you gain a better understanding of EMR and its interaction with matter.

A general observation about these interactions is the closer the EMR wavelength is to the size of the structure being investigated the greater the interaction between the EMR and the matter being studied. This means you get more information from the result of the interaction.

The following websites are outstanding and provide information on the science behind the interactions different EMR frequencies have with matter.

- <http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html>
- <http://resources.yesican-science.ca/trek/radiation/final/>

Radio waves	Information
How is the radiation produced?	Oscillating electrons in a conductor
Natural sources of the radiation	Stars
Man-made sources of the radiation	Radio transmitters and Power transmission
Uses of the radiation	Communications
What is transparent to it? What can it pass through?	Most materials are transparent to radio waves. They pass through walls and people to get to your radio.
How does it interact with matter?	Causes electrons to oscillate in metals
How is it detected?	Radio-receivers, crystals

Microwaves	Information
How is the radiation produced?	Accelerating free electrons in a magnetron. Nuclear and electron spin.
Natural sources of the radiation	Stars and background radiation leftover from the Big Bang
Man-made sources of the radiation	Microwave ovens, radar, communications systems
Uses of the radiation	Heating and cooking. Radar and information transfer through air.
What is transparent to it? What can it pass through?	Most non-metals
How does it interact with matter?	Metals will strongly absorb microwaves causing electrical currents and heating. Microwaves interact with non-metals by causing the molecules to oscillate, producing heating.
How is it detected?	Silicon-diode rectifier crystals

Infrared (IR)	Information
How is the radiation produced?	Molecular vibration
Natural sources of the radiation	All matter
Man-made sources of the radiation	Heaters, light globes, motors etc.
Uses of the radiation	Radiant heating, remote controls. Infrared radiation penetrates the skin further than visible light and can therefore be used for photographic imaging of subcutaneous blood vessels.
What is transparent to it? What can it pass through?	Infrared is absorbed more strongly than microwaves, but less strongly than visible light.
How does it interact with matter?	The result of infrared absorption is heating because it increases molecular vibrational activity.
How is it detected?	Thermometers, nerves in skin, thermocouples.

Visible	Information
How is the radiation produced?	Electron transitions in atoms and atom vibration of high enough frequencies.
Natural sources of the radiation	Stars, fire, volcanoes, lightning, bioluminescence
Man-made sources of the radiation	Light bulbs, lasers, fluorescent tubes, fireworks
Uses of the radiation	To see with, produces electricity
What is transparent to it? What can it pass through?	Air, water, glass and some plastics
How does it interact with matter?	Strongly absorbed by most solid materials
How is it detected?	Eyes, photoelectric cells

Ultra violet (UV)	Information
How is the radiation produced?	Electron transitions in atoms
Natural sources of the radiation	Stars, such as our sun
Man-made sources of the radiation	Fluorescent tubes, arc welding
Uses of the radiation	Tanning and production of vitamin D in humans, security systems, sterilisation (killing germs).
What is transparent to it? What can it pass through?	Very little
How does it interact with matter?	Strongly absorbed in electron transitions. Ozone in the earth's upper atmosphere absorbs large amounts of UV and protects us on earth.
How is it detected?	Sunburn, photodiodes, bluepaper, UV sensitive beads

X-rays	Information
How is the radiation produced?	Electron collision with nucleus of some metals
Natural sources of the radiation	Stars
Man-made sources of the radiation	X-ray machines
Uses of the radiation	Medical imaging, molecular structure analysis, cancer treatment
What is transparent to it? What can it pass through?	Non-metals
How does it interact with matter?	Ionises
How is it detected?	Photographic film

Gamma rays	Information
How is the radiation produced?	Nuclear reaction
Natural sources of the radiation	Stars, radioactive decays
Man-made sources of the radiation	Fission and fusion processes
Uses of the radiation	Cancer treatment
What is transparent to it? What can it pass through?	All matter to some degree
How does it interact with matter?	Ionises matter
How is it detected?	Scintillator