

Synchrotron Investigations

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

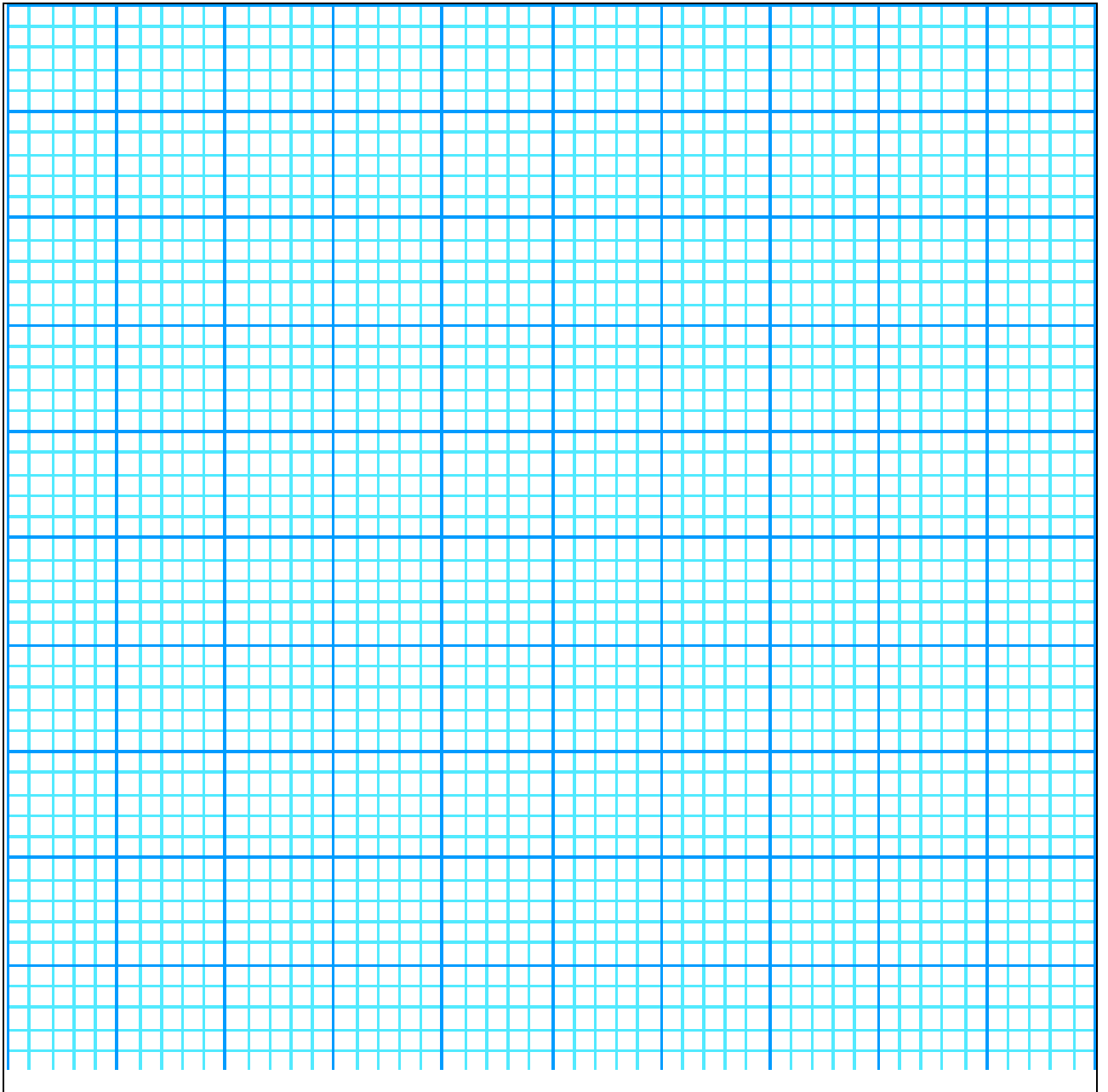
Einstein established that the speed of light (c) is a constant value in a vacuum.

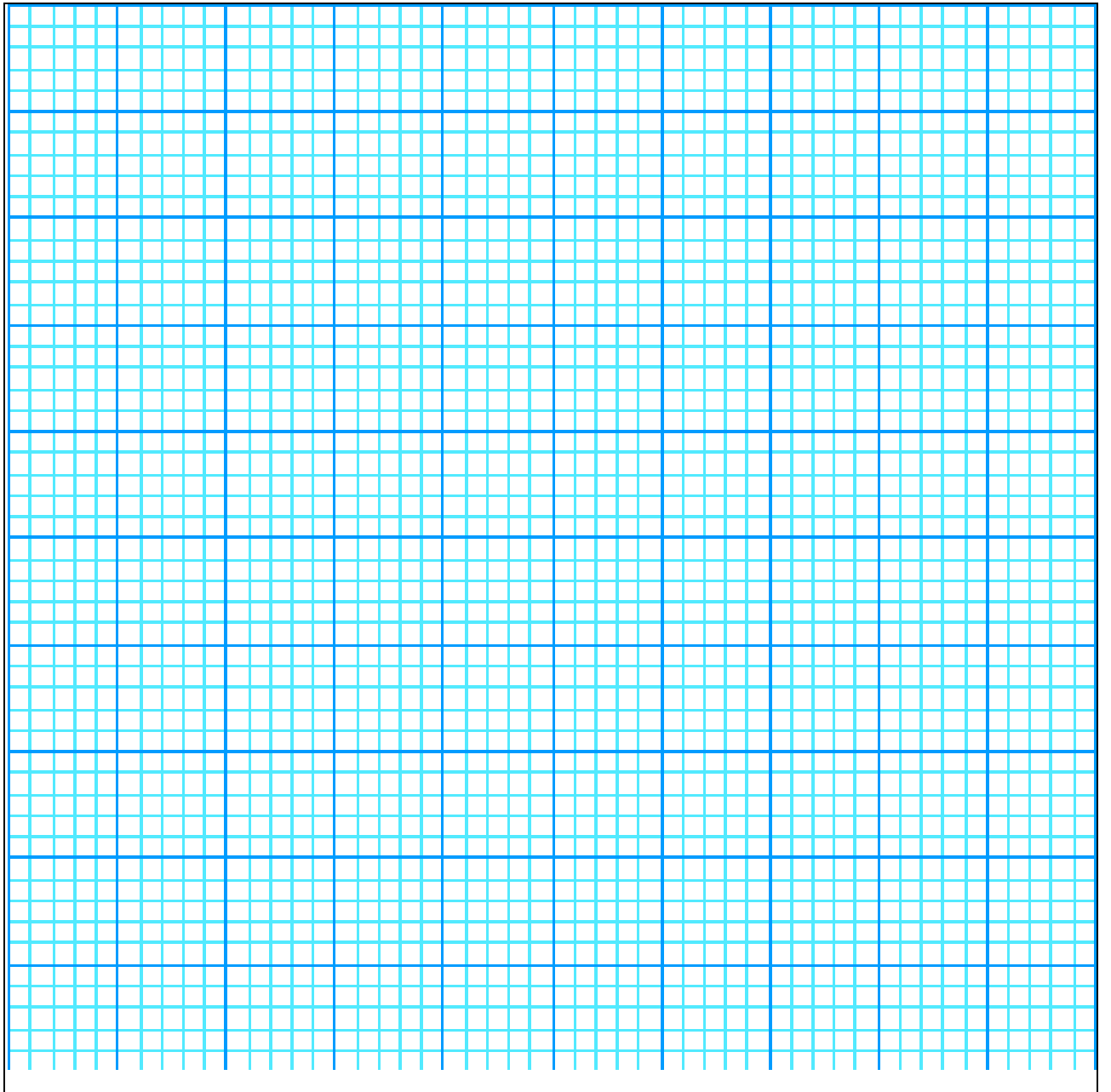
Using the *Electromagnetic spectrum explorer* and the relationship you established in the last activity, analyse data to find the speed of light.

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

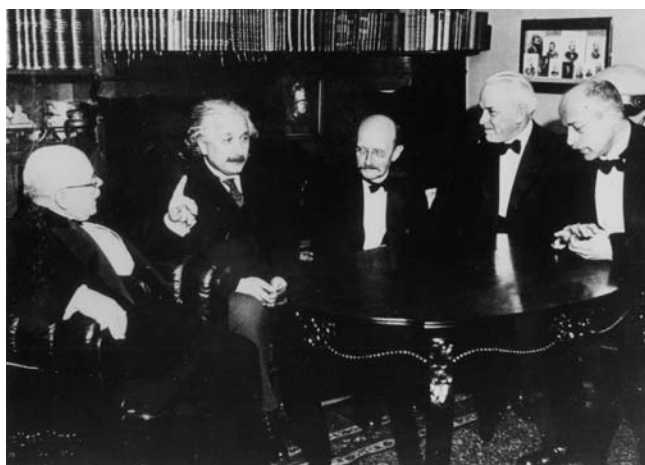
In 1900, Max Planck (1918 winner of a Nobel Prize in Physics) proposed a theory explaining how energy is absorbed and liberated by matter. At that time, people thought that energy flowed on a continuous basis in and out of matter.

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

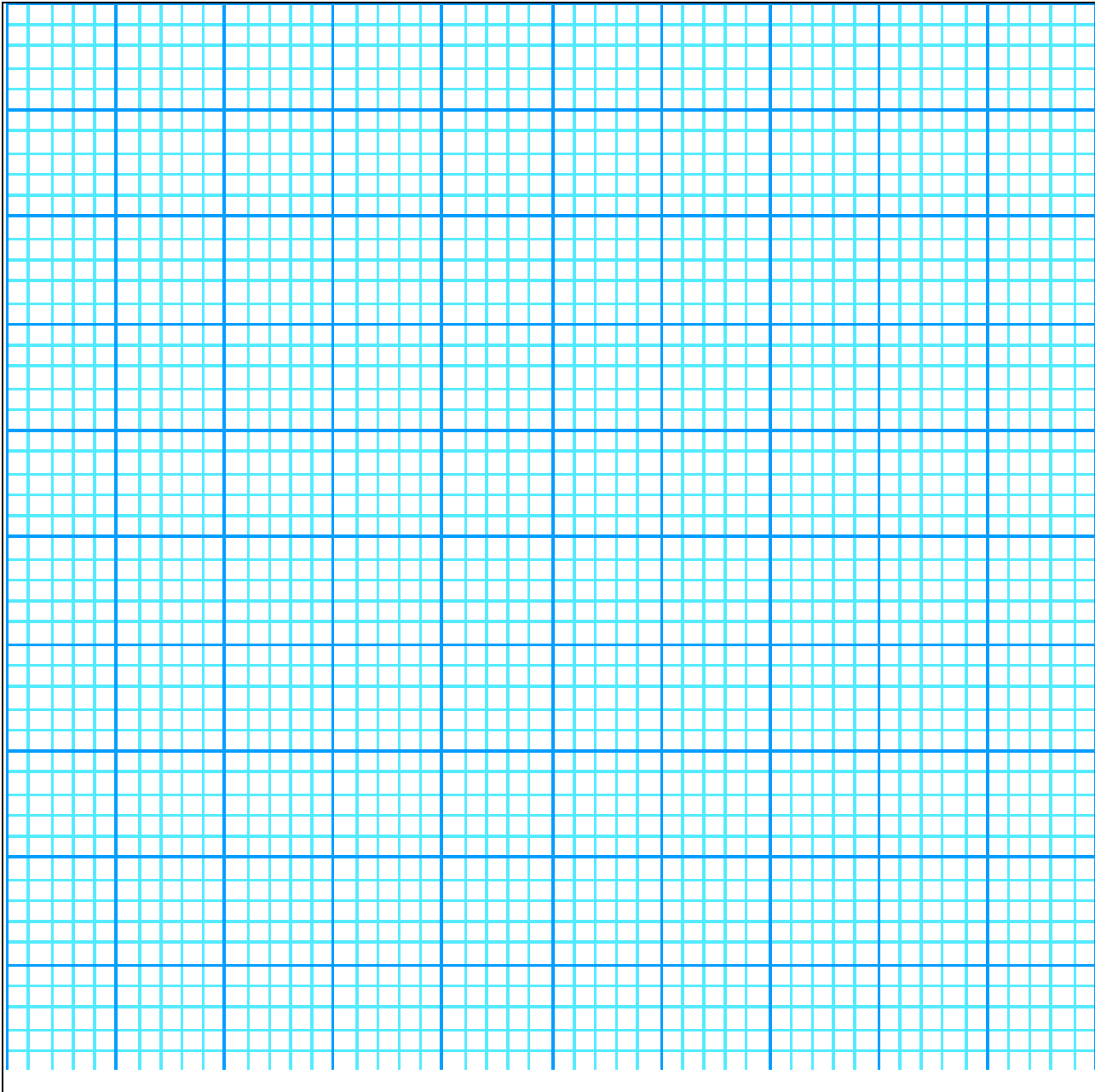
This story of three research scientists exploring the world through experiment and concepts is a great example of the importance of ‘basic research’ as contrasted with ‘applied research’. Basic research is experimental and conceptual activity for the sole purpose of extending human knowledge. Very little, 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.

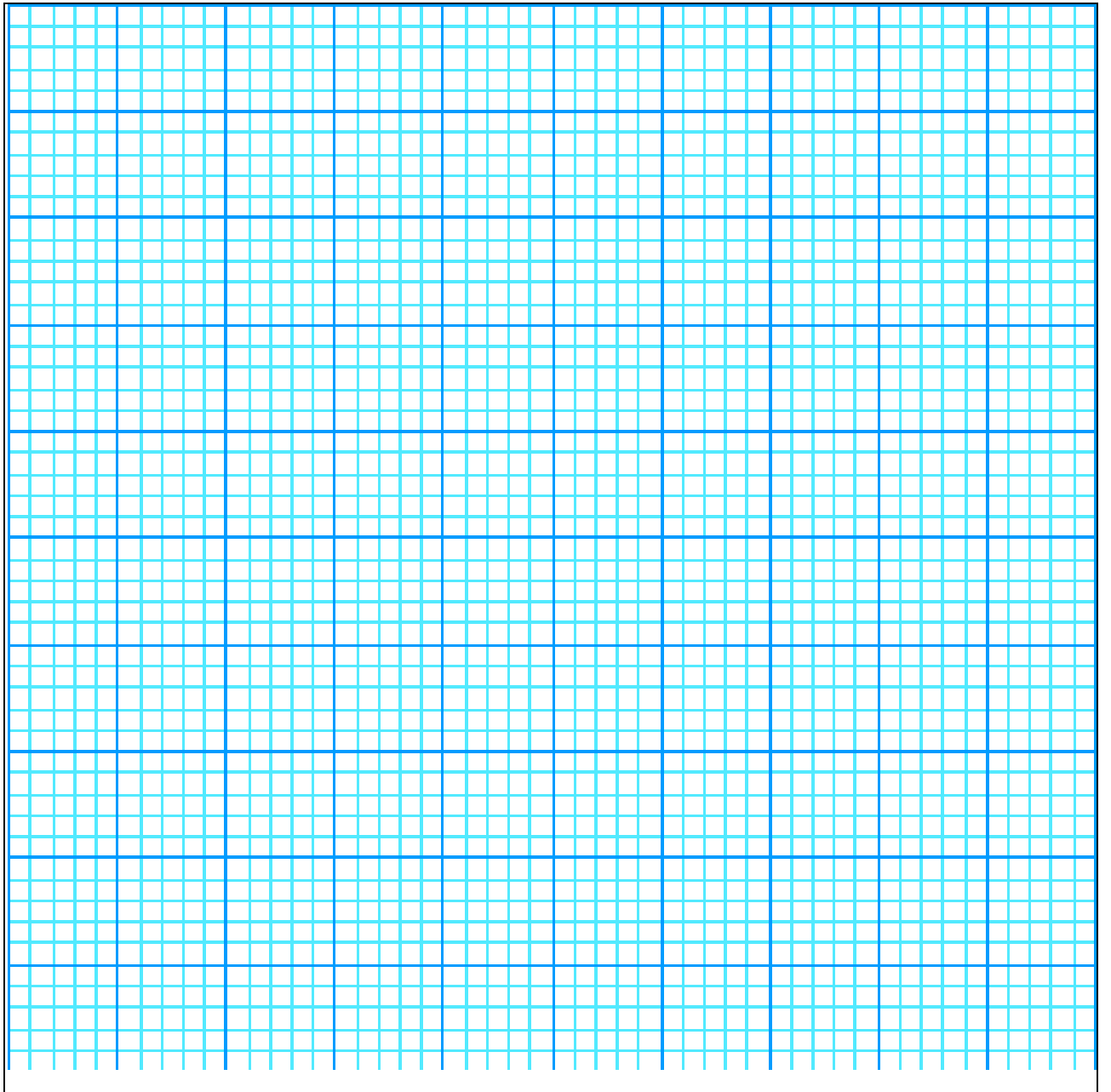
- Using your own knowledge and the information sheet '3.4 Interaction with Matter' complete the table below.

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: $E = hf$

