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# **The Electron**

### **The Electron**

'The electron is a theory we use; it is so useful in understanding the way nature works that we can almost call it real.'

• Nobel Prize winning physicist Richard Feynman

# Why is glass transparent?

#### **Properties of the electron**

- Orbits the nucleus
- Very small mass
- Negatively charged
- The charge on the electron is the smallest amount of charge found in nature\*.

You don't have to know the actual charge ( $1.6 \times 10^{-19}$  C), but you do need to know that the man responsible for first measuring this **charge** was **Robert Millikan**.

The term electron was coined by an Irishman called George Stoney.

**Thermionic Emission** is the giving off of electrons from the surface of a *hot* metal.

#### The Cathode Ray Tube\*



### Operation

- 1. A current is passed through the heating coil, causing it to heat the cathode which in turn causes electrons to be emitted (by thermionic emission).
- 2. Because of the high potential difference between the cathode and anode the electrons are accelerated across the tube towards the anode. As a result a current flows in the circuit.
- 3. Electrons which pass through the hole in the middle of the anode continue on until they hit the fluorescent screen.
- 4. The stream of electrons can be deflected by electric or magnetic fields, which are generated from the X and Y plates.
- 5. The voltage on the Y-plates is adjusted to make the cathode rays (or stream of electrons) move up or down.
- 6. The voltage on the X-plates is adjusted to make the cathode rays move left or right. The result is that the rays can move across the computer or television screen.

#### Uses of the Cathode Ray Tube

Basically it can be used anywhere a small electrical signal is produced.

1. Cathode Ray Oscilloscope (CRO). This is a variation of the cathode tube; it is used today in

electronics as a diagnostic tool.

- 2. It also forms the main component in (old-style) televisions and computers\*.
- 3. The ECG (electrocardiogram) is used in medicine\*\* to display electrical signals in the heart.\*\*

#### Cathode rays are streams of high-speed electrons

#### **Properties of cathode rays**

- They travel from the cathode in straight lines
- They cause certain substances to fluoresce
- They can be deflected in electric and magnetic fields
- They can produce x-rays when they strike heavy metals

### Energy associated with an electron\*

#### An electron's potential energy is given by the formula W= QV

#### • W = QV

This leads us to the concept of the electron-volt.

The Joule is a very large unit of energy relative to the energies involved at the atomic level, so physicists wanted to come up with a much smaller unit. After much deliberation, scratching of baldy heads and picking at patches on corduroy jackets, they decided the electron-volt was the right man for the job.

### The electronvolt (eV) \*

The electronvolt (eV) is the energy lost or gained by an electron when it accelerates through a potential difference of one volt.

From the formula W = qV, we can calculate that the energy lost or gained is  $(1.6 \times 10^{-19})(1)$ , or  $1.6 \times 10^{-19}$  Joules

#### Therefore

• 1eV =1.6 x 10 <sup>-19</sup> Joules

An electron's potential energy (W = QV) can be converted to kinetic energy (W =  $\frac{1}{2}$  mv<sup>2</sup>)

•  $QV = \frac{1}{2} mv^2$ 

### **Electrons in a magnetic field**

#### A beam of electrons moving at right angles to a magnetic field will move in a circular path\*.

We know (don't we?) that the force on a charge q moving at velocity v in a magnetic field B is given by

• **F** = **Bqv** → **F** = **Bev** (where e = charge on an electron)

We also know (from Chapter 12: Circular Motion) that when something is moving in a circular path at constant speed it experiences a centripetal force F, where

• 
$$\mathbf{F} = \mathbf{m}\mathbf{v}^2/\mathbf{r}$$

Now putting these two together we get:

#### • $mv^2/r = Bev$

Where m is the mass and r is the radius of the circle.

By rearranging this expression we can find the radius of orbit if we know everything else.

Note for each of the previous three equations v = velocity, not voltage

### **The Photoelectric Effect**

**The Photoelectric Effect** is the emission of electrons from a metal due to electromagnetic radiation of a suitable frequency falling upon it.

(electromagnetic radiation' is technical a better term to use than 'light'- can you say why?)

#### Demonstration



#### Procedure :

- 1. Charge a gold leaf electroscope negatively.
- 2. Shine ultraviolet light on the zinc plate.

#### Result :

The leaves fall together

#### **Observation** :

Shining UV light on the zinc plate liberates electrons from the zinc and therefore the legs become neutralised and fall back together.

#### **Einstein's Explanation**

"The body's surface layer is penetrated by energy quanta whose energy is converted at least partially into kinetic energy of the electrons. The simplest conception is that a light quantum transfers its entire energy to a single electron." - Albert E won his only Noble Prize for this work

- 1. The energy coming from the UV lamp travels in packets called 'photons'.
- 2. If the photons contain enough energy they can get absorbed by an electron on the surface of the zinc metal.
- 3. Each photon gives all its energy to one electron.
- 4. A certain amount of this energy (known as *the work function*) goes to *liberating* (releasing) the electron.
- 5. The remainder appears as kinetic energy of the liberated electron\*.
- 6. Shining visible light has no effect on the apparatus because the packets of energy associated with visible light are too small (frequency is too low) to liberate (release) electrons.

## This "proved" that electromagnetic radiation (including light) is composed of particles (called photons).

A photon is a bundle (discrete amount) of electromagnetic radiation.

### Mathematically: the photon as a packet of energy\*

The energy associated with each packet of energy (photon) is given by:

• E = hf

h is known as planck's constant (its values is  $6.6 \times 10-34$  J s) and f is the frequency of the wave.

According to Einstein's equation for the photoelectric effect (also known as *Einstein's photoelectric law*):

#### • Energy of incident photon = Energy required to free an electron + kinetic energy of photoelectron.

The energy required to free an electron (from the surface of an atom in the metal) is known as the *work function* of the metal and is given the symbol [] ("phi"). I have no idea why it is called *work function*.

 $hf = [] + \frac{1}{2}mv^2$ 

[] ("phi") is known as the work function.

It represents the energy required to 'liberate' an electron from the surface of a metal.

Because  $\Box$  is a discrete amount of energy, it can in turn be represented by the formula  $\Box = hf_0$ , where  $f_0$  is called the *threshold frequency*.

The value of the work function is different for different metals.

There are not many maths questions on this from the past papers, so it might be worthwhile to look at a textbook for lots more. The energy can be expressed in Joules or electronVolts (eV). If given in eV you will need to convert back to Joules.

Sometimes you will be given the wavelength of the wave instead of the frequency. Use  $c = f\lambda$  to work out f (where c is the speed of light).

### The Photocell

A diagram of a photocell is shown below.



In practice it is connected up in a circuit as shown in the diagram underneath.

#### Operation

- 1. Set up as shown
- 2. Light of a suitable frequency shines on *A* (called the cathode or photocathode).
- 3. This releases electrons (by the *photoelectric effect*).
- 4. The electrons are attracted to point B (the anode), and from there they flow around the circuit, where they can be detected by a galvanometer, or alternatively they can be used to activate an electronic device.
- 5. Note that if you bring the light source closer to the photocell there is now a greater intensity of light (more photons) falling on the cathode, which will result in the release of more electrons, as observed in a greater deflection in the galvanometer or ammeter.



#### Applications of photoelectric sensing devices

Controlling the flame in central heating boilers / automatic doors / fire alarms / photocells / photocopiers / light meters,

### **X-Rays**

**X-rays are produced** when high-energy electrons collide with a high density target.



#### **Operation of the X-ray tube**

- 1. The low voltage supplies power to a filament which in turn heats the cathode at A.
- 2. Electrons are emitted from the hot cathode due to thermionic emission.
- 3. They get accelerated across the vacuum due to the very high voltage and smash into the high-density anode (usually tungsten) at B.
- 4. Most of the kinetic energy gets converted to heat, which must be removed with a coolant.
- 5. Some inner electrons in the tungsten get bumped up to a high orbital, then quickly fall back down to a lower lever, emitting X-rays in the process.
- 6. These X-rays are emitted in all directions.
- 7. Most of these get absorbed by the lead shielding, but some exit through a narrow window, where they are then used for the required purpose.

#### A photon checks into a hotel and the porter asks him if he has any luggage.

#### The photon replies: "No, I'm travelling light."

#### **Properties of X-Rays:**

- They are Electromagnetic Waves
- They cause ionisation of atoms
- They have high penetration powers

#### **Uses of X-rays**

- Medicine: To detect broken bones
- Industry: To detect breaks in industrial pipes

#### Why can X-ray production be considered as the inverse of the photoelectric effect?

X-ray production: electrons are used to produce electromagnetic radiation

The photoelectric effect: electromagnetic radiation is used to release electrons

#### Hazards\*

They can ionise atoms in the body, causing them to become abnormal, which can lead to cancer.

### **Leaving Cert Physics Syllabus**

Content	Depth of Treatment	Activities	STS
1. The electron	The electron as the indivisible quantity of charge. Reference to mass and location in the atom. Units of energy: eV, keV, MeV, GeV.		Electron named by G. J. Stoney. Quantity of charge measured by Millikan.
2 Thormionic	Principle of thermionic emission	Use of cathode ray tube to	Applications
emission	and its application to the production of a beam of electrons. Cathode ray tube consisting of heated filament, cathode, anode, and screen. Deflection of cathode rays in electric and magnetic fields.	demonstrate the production of a beam of electrons – deflection in electric and magnetic fields.	<ul> <li>cathode ray oscilloscope</li> <li>television.</li> <li>Use of CRO to display signals:</li> <li>ECG and EEG.</li> </ul>
3. Photoelectric emission	Photoelectric effect. The photon as a packet of energy; $E = hf$ Effect of intensity and frequency of incident light. Photocell (vacuum tube): structure and operation. Threshold frequency. Einstein's photoelectric law.	Demonstration, e.g. using zinc plate, electroscope, and different light sources. Demonstration of a photocell.	Applications of photoelectric sensing devices: • burglar alarms • automatic doors • control of burners in central heating • sound track in films.
4. X-rays	X-rays produced when high- energy electrons collide with target. Principles of the hot-cathode X-ray tube. X-ray production as inverse of photoelectric effect. Mention of properties of X-rays: • electromagnetic waves • ionisation • penetration.		Uses of X-rays in medicine and industry. Hazards.

# Exam questions

Planck's constant =  $6.6 \times 10^{-34}$  Js; Speed of light =  $3.0 \times 10^8$  m s<sup>-1</sup>; Charge on electron =  $1.6 \times 10^{-19}$  C; Mass of an electron =  $9.1 \times 10^{-31}$  Kg

- 1. [2003][2003 OL][2005 OL][2006 OL][2008 OL] List two properties of the electron.
- 2. [2005 OL] Name another subatomic particle.
- 3. [2003] Name the Irishman who gave the electron its name in the nineteenth century.
- 4. [2002 OL][2009 OL] What is thermionic emission?
- 5. [2008] [2002 OL][2005 OL] Give two ways of deflecting a beam of electrons.
- 6. [2009 OL] What are cathode rays?
- The Cathode Ray Tube

- 7. [2005 OL]
- (i) The diagram shows a simple cathode ray tube. Name the parts labelled A, B and C.
- (ii) Electrons are emitted from A, accelerated across the tube and strike the screen. Explain how the electrons are emitted from A.
- 8. [2002 OL]
- (i) The diagram shows a simple cathode ray tube.Name the parts labeled A, B, C and D in the diagram.
- (ii) Give the function of any two of these parts.
- 9. [2009 OL] Why is there a high voltage between A and B?
- 10. [2002 OL][2005 OL][2009 OL] Give a use of a cathode ray tube.
- 11. [2007] How are electrons accelerated in a cathode ray tube?
- 12. [2005 OL][2009 OL] What happens when the electrons hit the screen?
- 13. [2003] What happens to the energy of the electron when it hits the screen of the CRT?
- 14. [2003]
- (i) An electron is emitted from the cathode and accelerated through a potential difference of 4kV in a cathode ray tube (CRT) as shown in the diagram.
  - How much energy does the electron gain?
- (ii) What is the speed of the electron at the anode?
- (iii) After leaving the anode, the electron travels at a constant speed and enters a magnetic field at right angles, where it is deflected. The flux density of the magnetic field is 5 × 10<sup>-2</sup> T.
   Calculate the force acting on the electron.
- (iv) Calculate the radius of the circular path followed by the electron, in the magnetic field.







#### The photoelectric effect

- 15. [2010] What is thermionic emission?
- 16. [2004 OL] Which one of the following is emitted from a metal surface when suitable light shines on the metal? protons neutrons electrons atoms
- 17. [2004] Distinguish between photoelectric emission and thermionic emission.
- 18. [2008][2005][2003][2005 OL][2008 OL][2010 OL]What is the photoelectric effect?
- 19. [2005][2006 OL][2009 OL][2010 OL]Give two applications of the photoelectric effect.
- 20. [2003 OL][2009]What is a photon?
- 21. [2008] Why as the quantum theory of light revolutionary?
- 22. [2002][2010 OL]Describe an experiment to demonstrate the photoelectric effect.
- 23. [2005][2002]Outline Einstein's explanation of the photoelectric effect.
- 24. [2005]Write down an expression for Einstein's photoelectric law.
- 25. [2008]High-energy radiation of frequency  $3.3 \times 10^{14}$  Hz is used in medicine. What is the energy of a photon of this radiation?
- 26. [2004]
- (i) Zinc metal is illuminated with ultraviolet light of wavelength 240 nm. The work function of zinc is 4.3 eV. <u>Calculate the</u> threshold frequency of zinc.
- (ii) Calulate the maximum kinetic energy of an emitted electron.
- 27. [2004]
- (i) A freshly cleaned piece of zinc metal is placed on the cap of a negatively charged gold leaf electroscope and illuminated with ultraviolet radiation.
- Explain why the leaves of the electroscope collapse.
- (ii) Explain why the leaves do not collapse when the zinc is covered by a piece of ordinary glass.
- (iii) Explain why the leaves do not collapse when the zinc is illuminated with green light.
- (iv) Explain why the leaves do not collapse when the electroscope is charged positively.
- 28. [2006 OL]

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.

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



29. [2003 OL]

#### The photocell

- (i) The diagram shows a photocell connected in series with a sensitive galvanometer and a battery.
  - Name the parts labelled A and B.
- (ii) What happens at A when light falls on it?
- (iii) What happens in the circuit when the light falling on A gets brighter?
- 30. [2008 OL]

A photocell is connected to a sensitive galvanometer as shown in the diagram. When light from the torch falls on the photocell, a current is detected by the galvanometer.

- (i) Name the parts of the photocell labelled A and B.
- (ii) How can you vary the brightness of the light falling on the photocell?
- (iii) How does the brightness of the light affect the current?
- 31. [2009]

An investigation was carried out to establish the relationship between the current flowing in a photocell and the frequency of the light incident on it. The graph illustrates the relationship.

- (i) Draw a labelled diagram of the structure of a photocell.
- (ii) Using the graph, calculate the work function of the metal.
- (iii) What is the maximum speed of an emitted electron when light of wavelength 550 nm is incident on the photocell?
- (iv) Explain why a current does not flow in the photocell when the frequency of the light is less than  $5.2 \times 10^{14}$  Hz.
- (v) The relationship between the current flowing in a photocell and the intensity of the light incident on the photocell was then investigated. Readings were taken and a graph was drawn to show the relationship.

Draw a sketch of the graph obtained.

- (vi) How was the intensity of the light varied?
- (vii) What conclusion about the nature of light can be drawn from these investigations?
- 32. [2003 OL] [2002 ][2008 OL] Give two applications of a photocell.







#### X-rays

- 33. [2006][2004 OL][2007 OL][2010]What are X-rays?
- 34. [2010 OL]Give three properties of X-rays
- 35. [2010]How do X-rays differ from light rays?
- 36. [2004 OL][2007 OL][2010 OL][2010]Give three uses of X-rays.
- 37. [2006]Who discovered X-rays?
- 38. [2002 OL][2002][2010]Draw a labelled diagram of an X-ray tube.
- 39. [2009]How are X-rays produced?
- 40. [2006][2005][2004 OL][2007 OL]How are the electrons emitted from the cathode?
- 41. [2006]How are the electrons accelerated?
- 42. [2004 OL][2007 OL]What is the function of the high voltage across the X-ray tube?
- 43. [2004 OL][2007 OL]Name a suitable material for the target in the X-ray tube.
- 44. [2007 OL]What happens when the electrons hit the target?
- 45. [2002 OL]Why is a lead-shield normally put around an X-ray tube?
- 46. [2010]
- (i) When electrons hit the target in an X-ray tube, only a small percentage of their energy is converted into X-rays. What happens to the rest of their energy?
- (ii) How does this influence the type of target used?
- 47. [2007 OL]Give one safety precaution when using X-rays.
- 48. [2010]
- (i) A potential difference (voltage) of 40 kV is applied across an X-ray tube. Calculate the maximum energy of an electron as it hits the target.
- (ii) Calculate the frequency of the most energetic X-ray produced.
- 49. [2006]
- (i) Calculate the kinetic energy gained by an electron when it is accelerated through a potential difference of 50 kV in an X-ray tube.
- (ii) Calculate the minimum wavelength of an X-ray emitted from the anode.
- 50. [2002]Justify the statement "X-ray production may be considered as the inverse of the photoelectric effect."
- 51. [2002 OL] The diagram shows a simple X-ray tube. Name the parts labelled A, B and C.
- 52. [2010 OL]What process occurs at the filament A?
- 53. [2010 OL] Name a substance commonly used as the target B
- 54. [2010  $\underline{OL}$ ]State the function of the part marked C



### **Exam Solutions**

- 1. Negative charge, negligible mass, orbits nucleus, no internal structure, deflected by electric / magnetic field etc.
- 2. Proton, neutron.
- 3. George Stoney
- 4. Thermionic emission is the emission of electrons from the surface of a hot metal.
- 5. By means of an electric field and a magnetic field.
- 6. Cathode rays are streams of high speed electrons.

7.

- (i) A =heating coil, B = cathode, C = anode
- (ii) The filament gets hot and thermionic emission occurs.

8.

- (i) A = filament/heater, B = cathode, C = anode, D = screen
- (ii) A heats the cathode.
  - B is the source of the electrons.
  - C attracts electrons.
  - D (fluorescent screen) detects electrons.
- 9. To attract and accelerate the beam of electrons.
- 10. Old-style televisions/ computer monitor, X-ray machine/oscilloscope /heart monitor/ECG.
- 11. By a the high positive voltage at the anode.
- 12. Light is emitted (the screen fluoresces).
- 13. It gets converted to light.
- 14.
- (i) The final kinetic energy gained by the electron equals the initial (electrical) potential energy  $= 4 \text{ KeV} = (4000)(1.6 \times 10^{-19}) = 6.4 \times 10^{-16} \text{ J}$
- (ii)  $E = \frac{1}{2} mv^2 \Rightarrow 6.4 \times 10^{-16} = \frac{1}{2} (9.1 \times 10^{-31})(v^2) \Rightarrow v = 3.75 \times 10^7 m s^{-1}$
- (iii)  $F = Bev = (5 \times 10^{-2})(1.6 \times 10^{-19})(3.75 \times 10^7) = 3.0 \times 10^{-13} N$
- (iv)  $F = mv^2/r$   $\Rightarrow 3.0 \times 10^{-13} = (9.1 \times 10^{-31})(3.75 \times 10^7)^2/r$

 $\Rightarrow$  r = 4.3×10<sup>-3</sup> m

- 15. It is the emission of electrons from the surface of a hot metal.
- 16. Electrons
- 17. Photoelectric Effect: Emission of electrons when light of suitable frequency falls on a metal.
  - Thermionic Emission: Emission of electrons from the surface of a hot metal.
- 18. The Photoelectric Effect is the emission of electrons from a metal due to light of a suitable frequency falling upon it.
- 19. Sound track in film, photography, counters, photocell, burglar alarm, automatic doors, etc.
- 20. A photon is a packet of electromagnetic radiation.
- 21. Light has a particle nature (as well as a wave nature)
- 22. Apparatus: gold leaf electroscope with zinc plate on top, ultraviolet light source
  - Procedure: Charge the electroscope negatively.

Shine ultraviolet light on the zinc plate.

Observation: The leaves fall together

23.

- Electromagnetic radiation consists of packets of energy which are called quanta or photons.
- The amount of energy in each quantum could be calculated using the formula E = hf.
- The incoming radiation needs to have sufficient energy to release an electron from the surface of a metal or it won't be absorbed at all. This amount of energy is known as the work function.
- If the incoming energy has more energy than an electron needs to be released (called its work function) then the excess energy goes to the kinetic energy of the electron.
- 24.  $hf = \phi + \frac{1}{2}mv^2$

25. 
$$E = ht$$
  
 $E = (6.6 \times 10^{-34})(3.3 \times 10^{14}) = 2.18 \times 10^{-19} J.$ 

- 26.
- (i)  $\phi = (4.3) \text{ eV} = (4.3)(1.6 \times 10^{-19}) \text{ J}$  $E = hf_0 \implies f_0 = E/h \text{ {where E is in joules }} \implies f_0 = (4.3)(1.6 \times 10^{-19})/6.6 \times 10^{-34} = 1.04 \times 10^{15} \text{ Hz}$
- (ii)  $c = f\lambda$   $\Rightarrow f = c/\lambda = (3.0 \times 10^8)/(240 \times 10^{-9}) = 1.25 \times 10^{15} \text{ Hz}$   $E_k = hf - \phi$  $E_k = [(6.6 \times 10^{-34})(1.25 \times 10^{15}) - (6.6 \times 10^{-34})(1.04 \times 10^{15})] = 1.39 \times 10^{-19} \text{ J}$

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27.
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- (i) Photoelectric emission occurs (electrons get emitted from the surface of the metal). The leaves become uncharged and therefore collapse.
- (ii) Ordinary glass does absorbs UV light
- (iii) The energy associated with photons of green light is too low for the photoelectric effect does not occur, so no electrons are emitted from the electroscope.
- (iv) Any electrons emitted are attracted back to the positive electroscope.

28.

- (i) Some of the excess electrons flow down to the bottom and the gold leaf moves away from the main section because similar charges repel.
- (ii) Many electrons are emitted from the zinc as a result of the ultraviolet radiation shining on it. Electrons from the main part of the electroscope flow up to replace this so there aren't as many electrons on the gold leaf to feel the repulsion.
- (iii) Infrared radiation will not have sufficient energy to release electrons so the gold leaf will not diverge to begin with.

29.

- (i) A is the cathode
  - B is the anode
- (ii) Electrons are released
- (iii) The current increases.

30.

- (i) A = cathode, B = anode
- (ii) Move it towards or away from the photocell.
- (iii) The brighter the light the greater the current.



- 31.
- (i) See diagram; A = cathode, B = anode
  - Also label glass case and vacuum inside
- (ii) The graph indicates that current only flows when the frequency of the radiation reached  $5.2 \times 10^{14}$  Hz, so this corresponds to the threshold frequency (f<sub>0</sub>).

 $\phi = hf_0 \qquad = (6.6 \times 10^{-34})(5.2 \times 10^{14}) = 3.432 \times 10^{-19} \text{ J}$ (iii) h(c/ $\lambda$ ) =  $\phi$  + ½mv<sup>2</sup>

 $(6.6 \times 10^{-34})(3 \times 10^{8}/550 \times 10^{-9}) = 3.432 \times 10^{-19} + \frac{1}{2} (9.1 \times 10^{-31})(v)^{2}$  $v = 1.922 \times 10^{5} \text{ m s}^{-1}$ 

- (iv) Because the frequency is less than the threshold frequency so does not contain enough energy to cause an electron to be released from an atom.
- (v) See diagram. Current is directly proportional to Intensity, so a straight line graph with the line going through the origin is required.
- (vi) Vary the distance from the light source to the photocell.
- (vii) Light is made up of discrete amounts of energy called photons.
- 32. Burglar alarm, smoke alarms, safety switch, light meters, automatic lights, counters, automatic doors, control of central heating burners, sound track in films, scanner reading bar codes, stopping conveyer belt, solar cells etc.
  Specific medical use e.g. X-ray photo, photo organs, destroy cancerous cells
  Specific industrial use e.g. detect cracks in metals, determine thickness of materials
- 33. High frequency electromagnetic radiation.
- 34. Electromagnetic waves / have short wavelength, ionise, penetrate, no mass, no charge, effect photographic film, cause fluorescence, diffraction, etc.
- 35. X-rays penetrate matter / cause ionization; light rays don't.
- <u>kTo</u> photograph bones/ internal organs, to treat cancer, to detect flaws in materials.
- X-rays were discovered by Wilhelm <u>Röntgen</u> in 1895 (shouldn't have got asked – not on the syllabus).
- See diagram; must include vacuum, cathode, target / anode and high (accelerating anode) voltage or H.T. / shielding / cooling / low (cathode) voltage or L.T.



- 40. The electrons are emitted from the cathode due to thermionic emission because the filament is hot.
- 41. By the high voltage between the anode and cathode.
- 42. To accelerate the electrons.



low voltage X-ray tube.

- 43. Tungsten
- 44. Some inner electrons in the tungsten target get bumped up to a high orbital, then quickly fall back down to a lower lever, emitting X-rays in the process.
- 45. For protection (to prevent X-rays entering the body).

46.

- (i) The energy gets converted to heat.
- (ii) The target material must have (very) high melting point.
- 47. Use a lead shield, lead apron, lead glass, monitor dosage.

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48.

(i) W = qV

W = (1.6 \times 10^{-19})(40 \times 10^{3})

W = 6.4 \times 10^{-15} J

(ii) E = hf

f = E/h

f = (6.4 \times 10^{-15})/(6.6 \times 10^{-34})

f = 9.7 \times 10^{18} Hz

49.

(i) E_{k}(=W) = q V = (1.6 \times 10^{-19})(50 \times 10^{3}) = 8.0 \times 10^{-15} J

(ii) E = h c/\lambda

\lambda = [(6.6 \times 10^{-34})(3.0 \times 10^{8})] / (8.0 \times 10^{-15})

50. X-ray: Electrons in, electromagnetic radiation is emitted.
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- Photoelectric: electromagnetic radiation in and electrons are emitted.
- 51. A = Cathode / heating coil, B = Anode (target), C = Lead shield
- 52. Thermionic emission / release of electrons // heating
- 53. Tungsten / molybdenum
- 54. Protection / shielding

### **Extra Credit**

About one hundred years ago, several remarkable and highly-important discoveries were crowded into the short space of ten years: X-rays in 1895, radioactivity the following year, the electron in 1897, quantum theory in 1900, and special relativity in 1905.

Individually, each had enormous significance and collectively they heralded what is now known as 'modern physics'.

**\*The charge on the electron is the smallest amount of charge found in nature** Physicists still don't know why an electron has the same charge as a proton!

Later on we will come across particles called quarks, some of which have a charge of 1/3rd that of the electron. But these are not found isolated in nature.

#### \*The Cathode Ray Tube

This phenomenon was noticed before people were familiar with the concept of the electron.

What was known was that if a fluorescent screen was placed on the inside of the tube, fluorescence would occur.

Therefore something seemed to be coming from the cathode.

Because the electrons could not be seen, this 'something' was called **cathode rays** , and the apparatus was called a **cathode ray tube**.

Incidentally, the cathode ray tube was first developed by Sir William Crookes, of Crooke's Radiometer fame (remember what that is?). Crooke was a major player in the world of physics in the late 19th century.

Crooke later lost all respectability among his peers due to his willingness to get involved in physic research (being able to read someone else's mind and all that). Crookes' final report so outraged the scientific establishment that there was talk of depriving him of his Fellowship of the Royal Society.

#### \*The Cathode Ray Tube forms the main component in televisions and computers.

For this the screen is divided up into little squares called 'pixels' (from 'picture elements').

The 'electron-gun' scans across each row of pixels, starting at the top left hand corner and working down, changing intensity as it travels.

Each pixel stays bright for a fraction of a second, but before it starts to fade the gun has gone back over it and 'refreshed' it.

The quality of a television screen is therefore determined by, among other things, the speed at which the gun travels, and the number of pixels on the screen. For example, a 640-by-480 pixel screen is capable of displaying 640 distinct dots on each of 480 lines, or about 300,000 pixels.

For colour televisions there are actually three 'guns' involved, each having one of the three primary colours, and the product of their relative intensities determine the colour seen on a given part of the screen.

'Course by the time you read this the cathode ray tube will probably be obsolete.

#### **Introduction to Quantum Theory**

Planck started the whole thing off, saying that heat was given off as little packets as opposed to continuous waves.

Einstein took this a step further and suggested that perhaps light was also given off in little packets (called photons) instead of as a continuous wave.

Planck, however, thought this was preposterous and could never accept Einstein's idea.

But Einstein also suffered a similar fate.

Predictability is one of the corner-stones of physics.

Resolving controversies in science usually involves successfully predicting the outcome of a speciallydesigned experiment.

But it turns out that in nuclear physics an atomic nucleus breaks down into other, smaller nuclei, and predicting when this will occur is impossible.

The best we can do is to give the *probability* of a break-down occurring.

Einstein, whose own work formed the foundation for these ideas, could never accept these conclusions.

In fact one of his most famous quotes was on this subject: "God does not play dice". What he meant by this is that the universe was not built around laws of probability (the reference to God was not meant to be taken literally – Einstein did not believe in a personal God).

For the record, all scientists now accept that probability does indeed lie at the heart of physics.

It gets better.

When formulating the rules for General Relativity – probably his greatest work of all – Einstein had assumed that the universe was static. i.e. it was not expanding.

This was in keeping with the belief at the time.

But one of the outcomes of General Relativity was that the universe was expanding. Believing that he had made a mistake somehow, he introduced a 'fudge factor' into his equations which stabilised the universe.

When the deliberate error was later discovered (by a postgraduate student) Einstein described it as 'the greatest mistake of my life'.

By this stage the inflationary universe was becoming accepted as the correct description of the universe, which in turn implied that the 'Big Bang' did indeed occur.

One of the many ironies in all this is that it is now thought that the universe may not go on expanding forever, but may indeed either stabilise or begin to contract again, resulting in the universe finishing in a 'Big Crunch'.

Either way, Einstein's fudge factor may not have been such a mistake after all.

Of course this was just when Einstein *acknowledged* he was wrong.

He also made a bit of a serious boo-boo when it came to trying to unify the four forces of Nature.

As a result of this he lost almost all respect among his peers, and spent the last decades of his career on a lone crusade which yielded nothing but the patronising sympathy of his fellow physicists.

Interestingly, Einstein seems to have paid very little attention to developments in physics (including the discovery of all the new particles) during these latter years

We will come across the concept of the four forces in more detail in the chapter on 'Particle Physics'.

By the way, one of the biggest advocates of the 'steady universe' scenario was a scientist called Fred Hoyle. Hoyle died recently, but in yet another irony, actually coined the term 'Big Bang' when he used it in a derogatory fashion.

The nerds among you may claim that this isn't actually an example of irony, but you know what I mean.