PHOTO ELECTRIC EFFECT - Planck's constant

Cat: AP2341-002 (Dual LCD meters, Lamp & Filters, expts 1&2)

DESCRIPTION: KIT CONTENTS:

- 1 pce. Photo-Electric Effect instrument. Runs from 9V transistor battery.
- 1 pce. 9V battery, type #216
- 1 pce. Lamp as light source, 12Volt, 25 Watt. Mounts on rear of unit. Spare lamp is Cat: PA2043-004 2pin, QI, 12V, 25W.
- 1 set of 5x Colour filters. Calibrated in nanometres wavelength.
- 1 set. 4x Apertures to set the quantity of light from the light source. Aperture orifices: 7mm, 10mm, 14mm, and 20mm diameters
- One test sheet and Experiment Sheets for using the instrument are included.

Features of this model:

- Dual meters permit the "backing voltage" and the photo-cell current to be viewed together without requiring the switching from one to the other.
- Removal of two selection switches also makes readings quicker and less confusing.
- This model includes selection of nanoamps or microamps as the current range for some of the experiments.

AP2341-002 Photo Electric Effect & Planck's Constant

Physical size: 272x160x110mm LxWxH **Weight: 1.3 kg**

THE ‘IEC’ PHOTO-ELECTRIC UNIT: description

A bench mounting instrument with 2 digital meters to simultaneously indicate both the current through the internal photo-cell and the backing voltage applied to the cell.

This model requires a 9V battery in the holder on the rear panel.

The image above shows the lamp mounted and the filters and apertures on the bench. They are normally stored in the container mounted to the panel. A small label lists the shortest wavelength (highest frequency) of light that can pass through each filter.

On the underside panel, an instruction label provides basic assistance to the user in the operation of the instrument to avoid unnecessary reference to the full set of instruction sheets.

Also the EXPT.1) is divided into several sections and each section is explained on the large information label.

Part of the study is to prove the discovery that the energy of photons depends on the wavelength of the light and not the amount or brightness

To avoid the use and possible loss of colour filters, IEC makes another model of the “Photo Electric” instrument AP2342-001 that uses LEDs of specific wavelengths as the light sources.

PRINCIPLE OF OPERATION:

Experiments can be performed in the following areas:

a) Photo Electric Effect … that light can create an electric current.
b) Illumination / Current relationship ... that current changes with luminous intensity.
c) Energy of a Photon … that a photon can drive an electron from a surface.
d) Planck's Constant … the amazing relationship between energy and wavelength.
e) Energy Distribution … where the energy is expended

The experiment sheets form a separate document, so in this small document we mention only the "Planck's Constant" experiment. Explanation is below:

When light falls on the cathode of the photo-cell, providing the energy level of the photon is high enough, the photon drives an electron from the metallic surface of the cathode. This electron has the energy imparted to it from the photon, therefore the higher energy of the photon, the higher energy of the electrons driven from the surface.

These electrons pass across the vacuum space in the cell to the Anode pin inside the cell. When a voltage is applied to the Anode in a direction to repel the electrons from the anode, the current flow completely stops as the last electrons of the highest energy levels cannot quite reach the anode. This voltage applied to the cell to stop the electron flow through the cell is called the "backing voltage". Therefore, the backing voltage that JUST causes this current to become exactly zero is a measurement of the energy level of the MOST energised electrons caused by the wavelength of the light applied to the cell.

It can be proven that the AMOUNT of light does not alter the energy level of the electrons, but, amazingly, the various wavelengths of the light alter the energy levels of the electrons. The graphing of the backing voltage against the frequency of the light for each of the 5 filter wavelengths creates a straight line proving a linear relationship between frequency of the radiation and the energy of its photons. The slope of this straight line multiplied by 'e' (charge on an electron) is the value of "Planck's Constant" ('h').

THE EXPERIMENT:

Slide the lamp housing into the slots on the rear face of the instrument and connect the 4mm banana plugs to a 12V AC or DC power source. Insert the blue filter.

Select Experiment 1 using nanoamps (nA) and turn ON the front panel switch so that the displays will show values.

Set the FINE control to about 'half' position. Using the COARSE control, adjust the BACKING VOLTS until the NANOAMPS reading is very close to zero. Then use the FINE control to achieve exactly zero nanoamps. Wait several seconds to be sure it is exactly zero. Take note of the BACKING VOLTS reading for the colour filter being used in front of the light source. Repeat the measurement to get an average.

Repeat the above for each colour filter in turn and note the backing volts in each case. Each time, repeat the measurement once or twice to obtain average volts.

Graph the results with the 'X' axis scaled as frequency of the colour in Hz $x10^{14}$ and the "Y" axis as backing volts in volts, then plot each relationship. Draw a straight line graph of best fit through the 5 points.

Planck's Constant ('h') is the SLOPE of this line (dV/df) x the charge on an electron ($1.6x10^{-19}$ coulombs). Theoretically, this value of 'h' = $6.626x10^{-34}$

FRONT PANEL CONTROLS:

ON/OFF SWITCH When ON, the digital displays will show digits.

- **'WAVELENGTH' OF THE COLOUR FILTERS:**
  The unit for wavelength is 'nanometres' = Metres $x10^{-9}$. Abbreviation: 'nm'.

  Frequency is: (3,000 / nm) $x10^{14}$' Unit is: Hertz (Hz)

- Blue: 432 nm wavelength (or 6.944 $x10^{14}$ Hz frequency)
- Green: 477 nm wavelength (or 6.289 $x10^{14}$ Hz frequency)
- Yellow: 501 nm wavelength (or 5.988 $x10^{14}$ Hz frequency)
- Orange: 522 nm wavelength (or 5.747 $x10^{14}$ Hz frequency)
- Red: 582 nm wavelength (or 5.155 $x10^{14}$ Hz frequency)

- **'BACKING VOLTS"– COARSE / FINE ROTARY CONTROLS:**
  Adjusts the DC volts applied to the anode and cathode of the photo cell attempting to completely stop the flow of electrons from the cathode to the anode. The value of this voltage is a measurement of the energy level of the electrons that relate to the selected wavelength of the light. The "coarse" control adjusts the voltage rapidly.

  The "fine" control adjusts the voltage more slowly to determine exactly zero current flow (zero electrons reaching the anode).

- **'VOLTS" AND "NANOAMPS" METERS:**
  The VOLT meter displays the value of the backing voltage required to bring the photo-cell current to exactly zero. This voltage value is graphed against the frequency of the light to determine Planck's Constant.

  The NANOAMPS meter displays the small current passing through the photo-cell down to 0.1 nanoamps (amps $x10^{-10}$). 1 nanoamp = $1/1000^{th}$ of 1 microamp.

- **'EXPERIMENT SELECTION: 1 OR 2:**
  Exp.1 permits 1a, 1b, 1c, 1d and 1e. Some require nA and others require uA measurements and this can be selected. EXPT.1) experiments relate to Photo Electric and Planck's Constant. EXPT.2) is for Characteristic curve of Photo Tube.

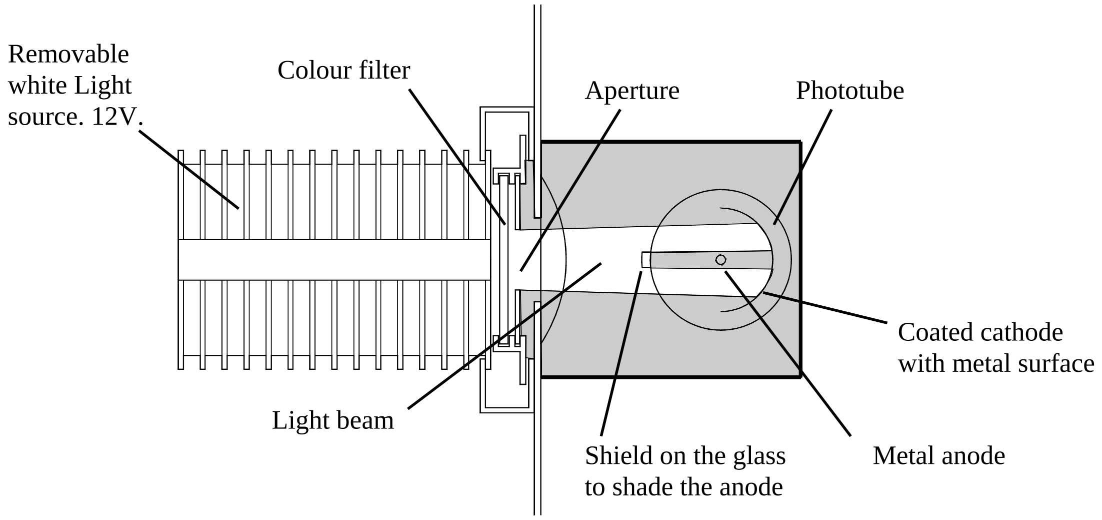
- **BRIGHTNESS OF THE LIGHT:**
  To adjusts the brightness or intensity of the light coming from the light source, take an aperture and slide it into the slot in front of the filter to change the orifice. The change of light intensity is to prove the proposal that it is not the amount of light that governs the energy levels of the electrons driven from the cathode of the photo-cell by the photons, but it is the wavelength of the light. The energy level will be found to be close to the same at both high and low light intensity levels.

NOTE: IEC produces an "experiment sheet" outlining the use of the equipment and the experiments to be performed.

Developed, designed and manufactured in Australia

THE PHOTOTUBE:

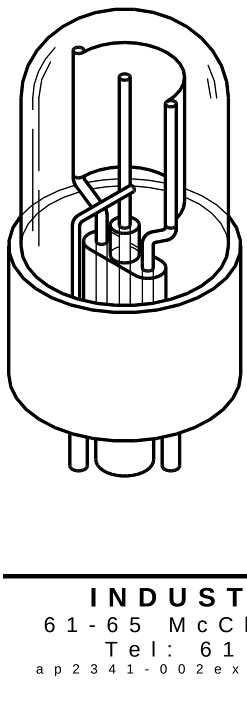
The phototube is the essential part of the instrument. It is an evacuated glass tube containing an electrode shaped like half of a cylinder. At the open mouth of this electrode, another electrode, in the form of a straight rod, is positioned at approximately the focal point of the curved surface.



THE ANODE: Light enters the tube to illuminate the cathode. The anode is a metal rod to which the electrons flow and it too is illuminated because it stands in front of the cathode. This bombardment of the anode with photons causes the metal surface of the anode rod to release some electrons (an unwanted Photo Electric Effect). Light is reflected also from the glass envelope and from the curved cathode surface itself back on to the anode rod. This anode emission must be avoided because it will spoil the normal migration of the electrons from the cathode surface to the anode and therefore create an error when measuring the exact backing voltage required to stop the electron flow from cathode to the anode.

To reduce this error, a shield is fitted to the glass envelope of the tube to shield the anode rod from direct light. The reflections inside the tube cannot easily be avoided.

THE CATHODE:



The curved surface of the cylinder is called the Cathode and is coated with a special compound that easily releases electrons when light (or photons) strike the curved surface. This coating is usually Caesium (or cesium) and Antimony deposited on silver oxide.

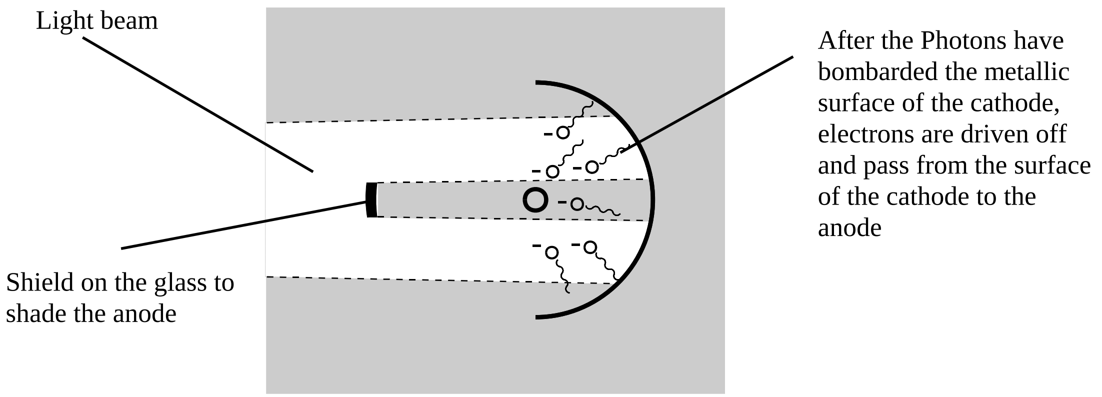
This material is used because it easily releases electrons when its surface is struck by photons.

When light strikes the metallic surface, the energy contained in a light Photon is passed to an electron which must first rise to the surface of the cathode material, then overcome the tendency to remain on the surface and finally burst off the surface to travel through the vacuum towards the anode rod.

While light is falling on the cathode, this is occurring billions of times per second and thus an extremely small current is constantly flowing between the cathode and the anode.

This current can be several millionths of an amp (microamps).

ELECTRONS INSIDE THE PHOTOTUBE:



THE PURPOSE OF THE PHOTON ENERGY EXPERIMENT:

To measure the energy of Photons, we need to detect but do not need to measure the current through the phototube. Photons of different energy excite electrons to different energies. The experiment is to **determine the highest energy level** to which the electrons have been excited by the Photons. There will be only a small percentage of electrons flowing from cathode to the anode with these highest energies and we apply a small reverse voltage (anode negative and cathode positive) **JUST high enough completely stop the flow of electrons.** This reverse voltage is called the Backing Voltage and we need to know the voltage that just stops the last few electrons (those with the highest energy of all).

When **ALL** the electrons stop flowing (absolutely zero current) the voltage has repelled the electrons, including the ones with the highest energy acquired from the photons. It is the energy level of the **highest energy electrons** that interest us for the following reason:

The filters placed in the path of the white light will pass all frequencies of light below their CUT OFF frequency. Most wavelengths of light will drive electrons from the cathode but **the wavelength marked on the filter is the shortest wavelength (highest frequency) of light that can pass to the phototube so, to be sure we are checking the energy of this shortest wavelength, <u>we need to measure the backing voltage that stops the electrons with the highest energy.</u>**

This is why it is so important to find EXACTLY the backing voltage that is just high enough to stop the last microscopic flow of current. With zero backing voltage, the current flow through the tube may be several microamps. As the backing voltage is increased, the current through the tube reduces to less than a microamp. When it reaches 000.0nA, if the backing voltage is increased more, the current will begin to flow backwards because electrons begin to flow from the anode to the cathode.

For this experiment, nanoamps (nA) is selected on EXPT.1) switch. Then read the value of the Backing Voltage when the current is at 000.0 nA.

NOTE: 1 microamp is $1x10^{-6}$ Amp. 1 nanoamp is $1x10^{-9}$ Amp.

EXPERIMENTS 1c & 1d: RELATING TO PHOTON ENERGY:

A quick overview of the method:

With illumination on and a filter in place, we observe the current flowing and we find the backing volts that JUST stops the phototube current. We repeat with each filter and then plot the backing volts against the highest frequency of light that passes through the filter.

- We increase the backing volts to get exactly zero nanoamps current flow.
- When the current is at exactly zero, we note the BACKING VOLTS.
- We note the wavelength of the filter used and the backing volts required for that particular wavelength. The experiment is repeated twice using the same filter to obtain an **average reading** of the backing volts **for that wavelength**.
- We then take the next filter and repeat the exercise until all filters have been used.
- We then convert each wavelength to frequency in Hz and we plot a graph of Frequency (in Hz) on the X axis against the backing voltage (in Volts) on the Y axis.
- We discover that the energy of the highest energy electrons in each case is directly proportional to the frequency of the light in Hz. We know this because the line drawn through the points plotted on the graph is a straight line.

DISCOVER IT IS THE FREQUENCY OF THE LIGHT AND NOT THE AMOUNT OF LIGHT THAT DETERMINES THE ENERGY IN A PHOTON.

- While using any colour filter, reduce the amount of light passing to the phototube by inserting an aperture. Referring to previous data on that colour filter, we find that very close to the SAME backing voltage stops the current flow. We try more apertures and no matter how much light there is, the maximum energy that is transferred by Photons to the electrons is close to the same.
- Repeat the experiment using different colour filters and various apertures.
- This amazing and famous discovery was made by Maxwell Planck and Albert Einstein and it relates to the 'Quantum Theory'.

Notes on running the experiments: step by step:

1. Be sure the 9V battery is present in the battery holder. Switch instrument ON and select EXPT.1). Check the digital display is ON and with good normal contrast.

2. Slide the light source housing into the slots that hold it close to the rear of the instrument. Connect the banana plugs to a 12V supply and turn light source ON.

3. Some experiments require the microamp (uA) setting for meter range and others require nanoamps (nA) setting. If the current over-ranges the nA setting, switch to uA setting. As the backing volts are increased, first by the COARSE control and then by the FINE control, the current through the tube will reduce until, using nA range, at exactly zero on the meter we can accept that as the electron flow through the tube has stopped.

4. The light source will be illuminating through the aperture in the rear face of the instrument. Note that the light source will become warm. **This is normal, but do not allow the light source to run for very long periods unattended or overheating may occur.**

5. Now insert one of the filters into the wider pair of the slide grooves provided in front of the light source. Do not fit any apertures.

6. increase the Backing Volts using the COARSE control until the current (electron flow) through the tube reads close to zero nanoamps, then use the FINE control to adjust volts to achieve 0.0 nanoamps through the tube.

7. Observe the Backing Volt reading that is being applied to the phototube in reverse to stop all electrons from reaching the anode. **Take note of both the wavelength of the filter used and this backing volt reading.**

8. Repeat 6) and 7) two more times. Using the same colour filter, calculate the average value of the backing volts that just completely stops electron flow. Note this value for that filter.

9. Remove the colour filter and change to another. Repeat the experiment from step 6) to step 8).

THE MATHS:

Distance (in nm) light travels per second / wavelength in nm = frequency in Hertz (Hz)

Speed of light is approximately 3×10^8 metres/second. 3×10^{17} nm/second.

Dividing this by wavelength (say 500nm) is an awkward number 0.006×10^{17}

It is easier for plotting to use 6×10^{14} This explains that to obtain a convenient value for plotting a graph, the formula becomes 3,000 / wavelength in nm = Hz x 10^{14}

From the wavelength (in nanometres) as marked on each filter, calculate the frequency (in Hertz) of the light transmitted by each filter used and plot a graph of frequency in Hz (X axis) to backing volts in Volts (Y axis) for each filter.

You should find that all points will fall on a straight line and the gradient of this line is related to **'Planck's Constant'**. From the graph, determine the value of Planck's Constant.

Also from the graph, the following can be determined:

- The cut-off frequency of the tube.

  This is the minimum frequency of light that drives any electrons at all from the surface of the cathode.

- The Work Function (‘W’) of the tube.

  This is the energy from the photons that is used in performing work on the electrons before electrons are driven free of the cathode surface to pass through the vacuum to the anode.

helpful information:

- The light source provided with the instrument is the Incandescent (simple glowing filament) type which does not have a very short wavelength component (not very much blue or violet content).

  If a mercury vapour (m/v) light source is used, a plain glass filter will be required to remove the Ultra Violet content from the light while leaving the shortest visible wavelength present (about 390nm).

  If using a mercury vapour lamp, remember that ambient light can enter the instrument when the original light source is removed from its mounting. Only light from the m/v lamp should enter the instrument. Be sure to use an opaque cloth or similar to eliminate ambient light from the instrument.

  This m/v wavelength will provide you with a 6th point to plot on the graph.

- If the light source is run at a lower voltage than 12V.AC/DC., the colour of the light will become more reddish. It might be found that the shorter wavelength may begin disappearing from the light and higher backing voltage figures for these wavelengths may not be possible. To maintain a reasonable amount of blue colour in the light source it is important that the lamp is operated at its full voltage of 12V AC/DC. If the voltage is too low, the light will become more reddish and the blue content of the light will diminish.

EXPERIMENTS: The experiments that can be done are:

- 1a: Demonstrating the Photo-Electric Effect.
- 1b: Relationship between tube illumination and tube current.
- 1c: Demonstrating that Photon energy is dependent on frequency of the light.
  . Demonstrate also that it is a linear relationship.
- 1d: Determining Planck's Constant from a graph.
- 1e: Examining energy distribution of the electrons in the tube.
- 2: Determining the characteristic curve of the phototube
- **Discussion:** Is light really a **particle** or an **electromagnetic wave** ?

EXPERIMENT 1a: THE PHOTO-ELECTRIC EFFECT

Our laboratory for these experiments is a Phototube which is a special metal surface and a metal anode both mounted in a vacuum inside a glass envelope. It is said that when Photons of light strike some metallic surfaces, each Photon transfers all of its energy to an individual electron which then has sufficient energy to be released from that metallic surface. Some of the Photon's energy is used up in raising the electron to the surface of the metal and energy is used up in releasing the electron from the electrostatic pull of the surface of the metal.

The remaining energy drives the free electron from the cathode to the anode inside the vacuum tube. This phenomenon is known as the 'Photo-Electric Effect' and provides the basis for several experiments involving the energy levels of light particles.

The 'IEC' Photo Electric Effect apparatus is fully self contained and includes the electronics for detection and amplification of the very small currents involved (nanoamps).

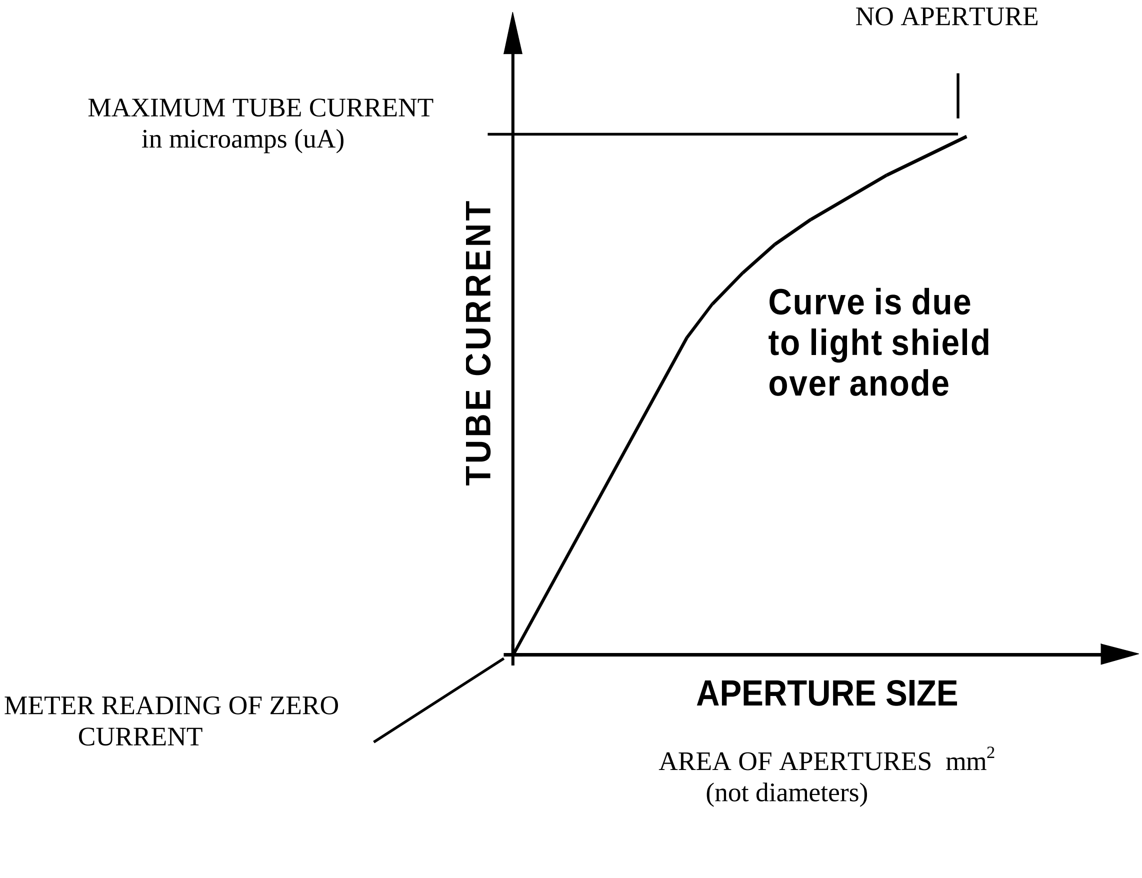
There is no voltage applied to the Phototube, but the light from the light source mounted on the rear face of the instrument will fall upon the surface of the cathode of the sensitive phototube contained within the apparatus. Electrons are excited and escape from the surface of the metallic cathode to migrate to the anode. This constitutes a very small current of electrons between the cathode and the anode and this current is detected and amplified to be seen on the meter.

- **Select Experiment 1 and uA (microamp) range. Turn power ON.**
- **Turn COARSE knob anti-clockwise to set Backing Volts to ZERO.**
- **Fit light source to the rails at the back of the instrument and turn light on. The meter will show microamps of current flowing through the tube caused by photons from the light source striking the cathode surface and driving off electrons.**

At this point it can be said that the Photo-Electric effect has been demonstrated.

EXPERIMENT 1b: relationship between ILLUMINATION & CURRENT

- With the light source in place as in the previous experiment and with the Backing Volts set to zero, select uA (microamps) and observe the phototube current altering as the different apertures ov various areas are inserted into the path of the light beam. The apertures in the kit must be changed to rectangular vertical slots about 6mm wide so that all the light passing from the aperture strikes the tube's cathode. Stick some thin card each side of the round holes to narrow them down to 6mm wide vertical slots. Measure their areas in sq.mm.
- These slot apertures are inserted into the narrower set of slide grooves just in front of the light source. The instrument is designed to accept both a filter and an aperture at the same time. This combination is used in other experiments.
- Plot a graph of current through the tube (in microamps) against aperture area which is (pi x (aperture radius)^2). It will be obvious that with less total light, the current from the cathode reduces as less electrons are released by the photons striking the cathode.
- The graph should extend in a straight line to zero aperture and zero tube current.



EXPERIMENT 1c: THE ENERGY IN A PHOTON DEPENDS ON THE FREQUENCY OF THE LIGHT

Now the light from the light source is passed through colour filters supplied in the kit so that the shortest wavelength passing is known (each filter is marked with the shortest wavelength it can pass). This light falls upon the surface of the cathode of the sensitive phototube contained within the apparatus. When photons fall upon the metallic surface of its large curved cathode, photons transfer their energy to the electrons and the excited electrons escape from the surface of its metallic cathode to migrate to the anode. This constitutes a very small current of electrons between the cathode and the anode and this current is detected to be seen on the meter.

The energy of the electrons can be determined by applying a small voltage to the tube in the reverse direction to determine the voltage that stops ALL the electrons from flowing from the cathode to the anode. When the current is no longer flowing, the value of this voltage is a measurement of the level of energy of the **most energetic** electrons. **This means the electrons that were excited by the Photons of the highest frequency (shortest wavelength) component of the light beam entering the phototube.**

As different filters cause different wavelengths of light to be the highest frequency, it is found that it takes a different backing voltage to stop the current created by the different wavelengths. Therefore the energy of the photon that was transferred to the electron depends on the wavelength of the light.

By using the different sized apertures, it can be discovered that if the AMOUNT or brightness of light is increased or decreased, it makes little or no difference to the backing voltage required to completely and exactly stop the electron flow. Therefore it follows that the energy in a Photon of light depends on the **wavelength** of the light and does not depend on the **amount or brightness of light.**

At this point it can be said that Photon energy depends on the wavelength of the light.

For each of the filters provided in the kit, the value of the highest frequency of the light reaching the phototube (X axis) is plotted against the Backing Voltage required to stop the flow of current (Y axis). It can be discovered that the line joining the points is a straight line

At this point it can be said that the energy of a Photon is proportional to the frequency of the light and its energy is higher for higher frequencies (shorter wavelengths).

DISCUSSION: A Photon is behaving like a particle when it transfers energy to an individual electron. Light behaves like a wave when it reflects or diffracts to create interference patterns through slits or gratings.

Discuss how light can be both a particle and a wave.

EXPERIMENT 1d: Analyse data to determine: PLANCK'S CONSTANT

The Theory: A photon of light has energy **'hf'**, as proposed by Einstein in 1905, where **'h'** is a constant and **'f'** is the frequency in Hertz of the radiated emission.

In the Photo-Electric effect, a Photon gives up all its energy to an electron in the surface of the illuminated material. The energy is used for three purposes:

- 1) Bringing the electron to the surface of the metal and 2) Freeing the electron from the metal's electrostatic attraction. The energy required to do all this is called the 'Work Function' **('W')** of the metal in the phototube.
- 3) Providing Kinetic energy to the free electron.

It follows then that for a given frequency, the most energetic electrons at the surface of the metal have kinetic energy 'T' **where: T (max) = hf - W** Where **'W'** is the **'Work Function'**, or the minimum amount of energy required for an electron to be released from the surface of the metal.

The constant **'h'** was first determined by **Maxwell Planck** so it is known as **Planck's Constant**. In the experiment, we must know the UPPER frequency of the light striking the metal surface in the phototube. To do this, filters are inserted in the light path. These special filters cut off all light at any wavelength shorter than the wavelength marked on the filter frame. Remember: short wavelength means high frequency.

Each Photon will lose all its energy to an electron in the surface of the metal and the maximum kinetic energy of the electrons can be determined by applying a reverse voltage to the tube so that a retarding electric field **JUST** completely stops the most energetic electrons from reaching the anode. This reverse voltage is called the 'Backing Voltage'.

If this 'Backing Voltage' has a value **'V'**, then the energy supplied by the electric field in stopping the emitted electrons from reaching the anode is **'eV'**, where **'e'** is the charge on the electron and **'V'** is the backing voltage. This energy equals the kinetic energy of the electrons, so since **T (max) = eV** then it follows that **eV = hf - W**

For different wavelengths of light, a graph of **'V'** as a function of **'f'** can be plotted. Its **gradient** will be the **change of 'V' / the corresponding change of 'f'**.

Divide both sides of formular by 'e' gives V = hf/e - W/e or **V = f(h/e) - W/e**

This follows the normal straight line formula of: y = ax + b

So, the slope of the V/f graph will be h/e and the intercept on the Y axis will be -W/e

If the gradient is calculated from 'ΔV' and 'Δf', then the value of Planck's Constant 'h' can be found because the value of 'e' is known at 1.6 x 10^{-19} coulomb.

MEASURING THE WORK FUNCTION: The Work Function W/e = f(h/e) - V

Multiply through by 'e'. W = fh – Ve

EXPERIMENT 1d: FURTHER INFORMATION:

To obtain the frequency of the light in Hertz from its Wavelength in nanometres (metres x 10^{-9}), divide the speed of light by its wavelength. Accept the value of 'c' (speed of light) as 3 x 10^{8} metres / second.

EXAMPLE: For a wavelength of 428 nm, the frequency would be:

$$f = 3 \times 10^{8} / 428 \times 10^{-9} = 7.0 \times 10^{14} \text{ Hertz}$$

Typical tabulated results:

Filter Colour	*Shortest Wavelength*	*Freq.passed. Hz x 10^{14}*
Blue	**432 nm**	6.944
Green	**477 nm**	6.289
Yellow	**501 nm**	5.988
Orange	**522 nm**	5.747
Red	**582 nm**	5.155

Plain glass in the light path absorbs all the ultraviolet, leaving the shortest wavelength transmitted to be the violet line (390 nm.). **Accept the charge on an electron as 'e' equal to 1.6 x 10^{-19} coulomb**

To calculate the kinetic energy 'T' of the electrons in electron volts, multiply 'e' by the backing voltage 'V'. The gradient of the graphed line is any change in the value of 'V' in volts divided by the corresponding change in value of 'f' in Hertz.

THIS WOULD BE A PERFECT RESULT (but difficult to get):

If the tube performed perfectly and if there were no errors or electron collisions inside the tube and no anode emission, from the graph, the gradient should be about 0.41 x 10^{-14}

Follow this through:: Theory tells us that h / e = the gradient of the graph

so, h / (1.6 x 10^{-19}) = 0.41 x 10^{-14} therefore: h = 0.41 x 1.6 x 10^{-33}

so, h (Planck's Constant) = 6.6 x 10^{-34} joule seconds.

(Planck's Constant is considered to be: 6.626 x 10^{-34} joule seconds)

A TYPICAL RESULT: Due to factors inside the tube beyond our control and due to internally reflected light from the cathode on to the anode causing electrons to be emitted also from the anode, the gradient of the line is not exact**. Therefore, a typical gradient is usually about 0.33 to 0.38 instead of 0.41 (between 7% and 20% error).**

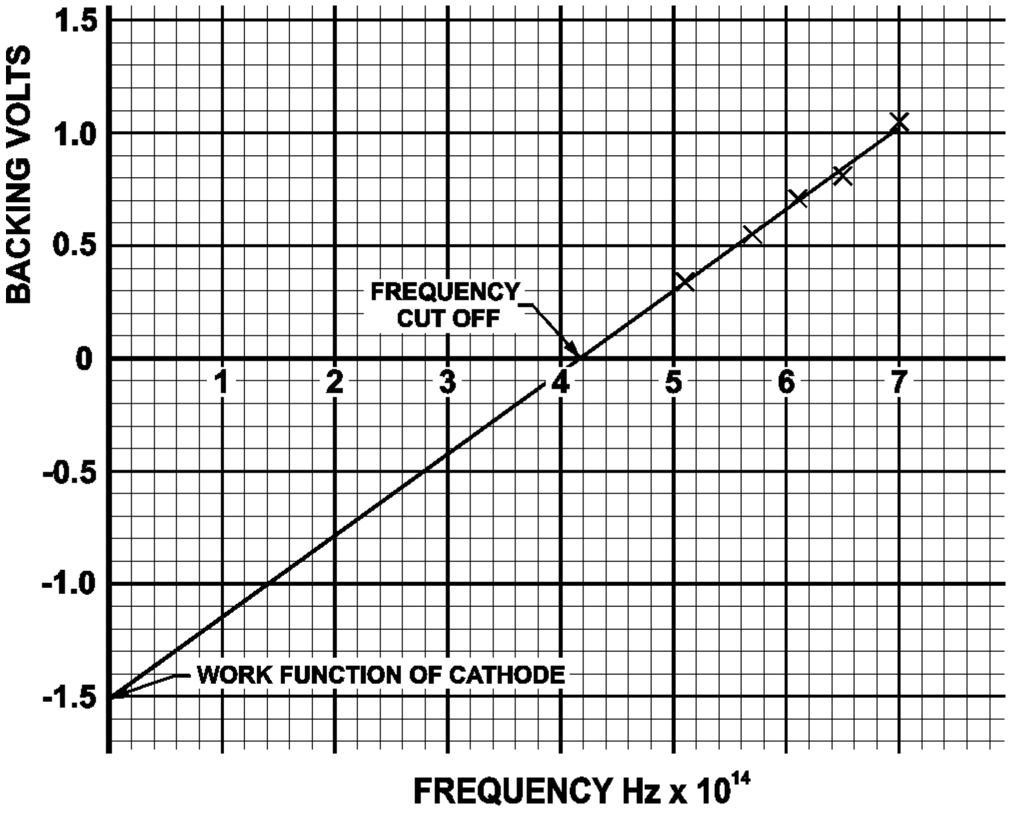
EXPERIMENT 1d: SAMPLE GRAPHS:

Typical experimental readings:

Wavelength	*Freq: Hz x 10^{14}*	*Colour*	*Backing Voltage*
432 nm	6.9	Blue	1.04 V
477 nm	6.3	Green	0.81 V
501 nm	6.0	Yellow	0.71 V
522 nm	5.8	Orange	0.55 V
582 nm	5.2	Red	0.34 V

Cut-off frequency (from the graph) = 4.17×10^{14} Hz.

Work function 'W' of the cathode (from the graph) = 1.5 eV.



Slope of graph = $\Delta V / \Delta f = 1.50 / 4.17 \times 10^{14} = 0.36 \times 10^{-14}$ = h/e

Calculate 'h': (slope) x (e) = $(0.36 \times 10^{-14}) \times (1.6 \times 10^{-19}) = 5.78 \times 10^{-34}$

Percentage error from Planck's constant: ((6.626 – 5.78) / 6.626) x 100 = 12.7%

Depending on the exact performance and efficiency of the Photo Electric tube, errors ranging from 8 % up to about 30% can be expected in calculating Planck's Constant. Nevertheless, the method and the theory is clearly demonstrated.

EXPERIMENT 1e: ENERGY DISTRIBUTION:

- Create a graph plotting relative current through the photo-tube against actual Backing Voltage. Remember that current is proportional to the number of electrons and Backing Voltage is proportional to their energy. Start with uA and change to nA.

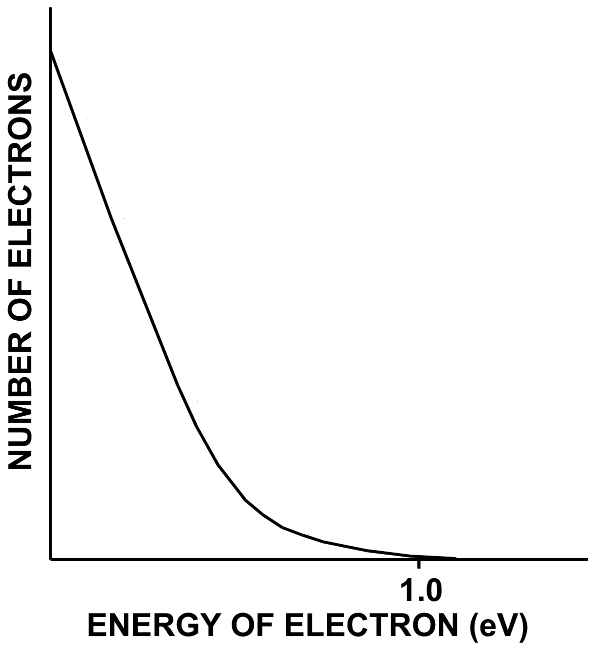
By considering the shape of the graph, deduce an energy distribution for the electrons.

Determine:

- What proportion of all the emitted electrons have the maximum energy (highest number of eV) ?
- What proportion have say up to half of the maximum energy ?
- What proportion have say 2/3rd the maximum energy ?

RESULT: Only a small proportion of electrons have high energy, most electrons have low to medium energy.

‘NUMBER OF ELECTRONS’
IS THE SAME AS CURRENT.



THIS IS THE VALUE OF BACKING
VOLTAGE APPLIED TO THE TUBE

EXPERIMENT 2: CHARACTERISTIC CURVE OF THE PHOTO-TUBE:

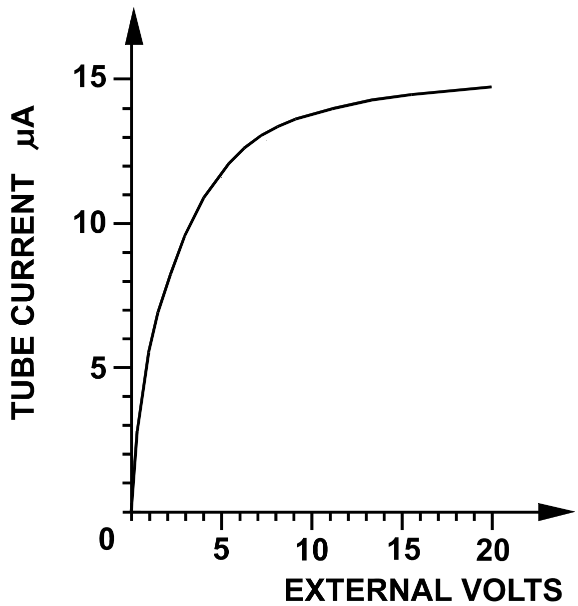
CURRENT / VOLTAGE CHARACTERISTIC OF THE TUBE:

Select Experiment 2 and connect the external sockets to an adjustable power supply that can provide 0- 20V.DC.and can provide at least a few milliamps. In this experiment the voltage is not a 'Backing Voltage' because, this time, the **voltage is applied to the tube in the forward direction to encourage electron flow from the cathode to the anode. This applied voltage can be monitored on the instrument's digital display.**

The experiment is to determine the characteristic of the tube by plotting applied voltage against the relative current through the phototube while white light is falling on the cathode. Do not use filters **<u>and use the smallest aperture for minimum amount of light.</u>** Gradually increase the applied voltage at the 4mm sockets from zero up to about 20V.DC.

With light falling on the tube, the tube current changes with applied voltage as shown in the graph below. Plot the relative phototube current in microamps against the applied forward voltage in Volts to obtain the **characteristic curve** of the phototube.

- Try to explain the shape and the reason for the 'flattening off' of the curve.



Developed, designed and manufactured in Australia