PHOTO ELECTRIC EFFECT - Planck's constant

Cat: AP2341-001 (LCD digital model with 5 filters)

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 to 30Watt. Mounts on rear of unit. Spare lamp is Cat: PA2043-004 2pin, QI, 12V, 25 to 30W.
- 1 set of 5x Colour filters. Calibrated in nanometres wavelength.
  428nm (blue) / 460nm (green) / 492nm (yellow) / 530nm (orange) / 590nm (red)
- 1 set. 4x Apertures to set the quantity of light from the light source.
  Aperture orifices: 7mm, 10mm, 14mm, and 20mm diameters

AP2341-001

Physical size: ***Weight:*** ***kg***

The 5x special filters and the 4x apertures store in a secure compartment at the rear of the instrument. The light source can run from any 12V power supply and all experiments can be run from this single light source. Special lights are not required.

For one of the experiments, an external student voltmeter is required.

At the rear of the instrument, a shutter can be removed to permit complete viewing of the photo tube for better understanding for the students.

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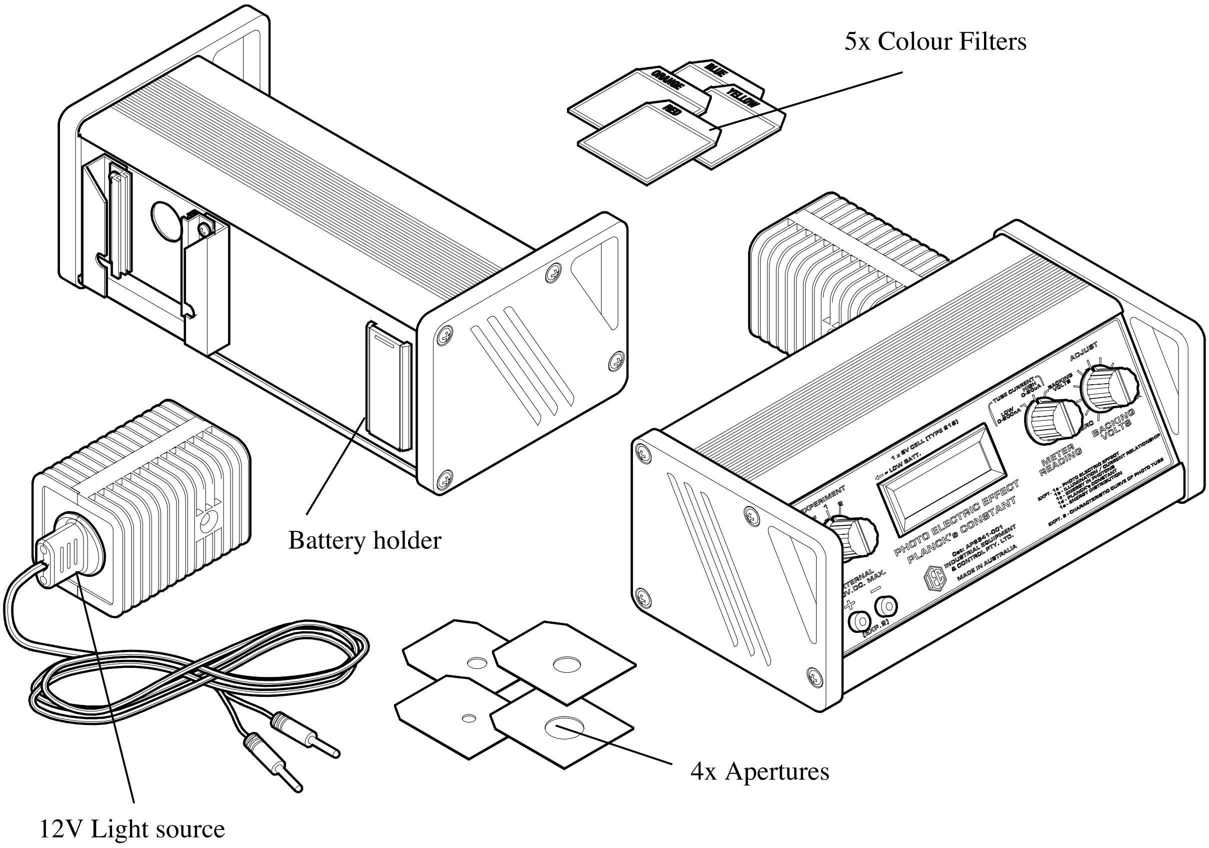
THE 'IEC' PHOTO-ELECTRIC UNIT: description

Bench mounting instrument with digital meter to indicate either current through the internal Phototube or voltage applied to the Phototube.

A 9V battery, provided with the instrument, must be fitted into the small battery holder or compartment (depending on model) in the rear face of the instrument.



Parts & accessories:

All parts are available as spares:

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FRONT PANEL CONTROLS:

- **'EXPERIMENT' ROTARY SWITCH (left of meter) 3 pos'n:**
  1) Turn battery power ON/OFF. When selecting an experiment, LCD display is on.
  2) Select Experiment 1 (parts a-e):
     a) Photo Electric Effect
     b) Illumination / Current relationship.
     c) Energy of a Photon
     d) Planck's Constant
     e) Energy Distribution
  3) Select Experiment 2: The Characteristic Curve of a Phototube.
- **'METER READING' ROTARY SWITCH (right of meter) 3 pos'n:**
  1) Select the digital meter to read very small current through the tube (0-200nA). . 1 nA (nanoamp) is 1x 10^{-9} amps. Reads to 0.1 nA.
  2) Select the digital meter to read larger current through the tube (0-20uA) . 1 uA (microamp) is 1x 10^{-6} amps. Reads to 0.01 uA.
  3) Select the digital meter to read the Backing Voltage applied to the tube. This Backing Voltage is adjustable from 0 to -1.8V. When Experiment 2 is selected, this switch position monitors the 0 to +20V applied to the tube from the External sockets.
- **'ADJUST BACKING VOLTS' ROTARY CONTROL:** When in Experiment 1, adjusts the backing voltage applied to the tube from zero to about 1.8 volts. The application of this voltage to the tube (backwards) is to reduce the current passing through the tube to zero nanoamps (amps x 10^{-9}). When Experiment 2 is selected, this control has no function.
- **'EXTERNAL' 4mm SOCKETS:** When Experiment 2 is selected, an external voltage **not exceeding 20V.DC.** can be connected to these sockets to perform the experiment dealing with the forward current characteristics of the phototube when illuminated. Although an external voltage is applied to the sockets, the 9V battery in the rear panel is still required for the instrument to run.
- **METER:** The digital meter is ON when power is ON. The meter reads as follows:
  Experiment 1: Reads the selected Current flow through the phototube of 0-20uA or 0-200nA, Reads Backing Volts applied to the tube as adjusted by front panel control, from 0 to -1.8V.

  Experiment 2: Reads the 0-20uA current flow through the phototube or reads the adjustable forward volts from 0 to +20V as applied to the tube from External sockets.

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BATTERY: On the rear face of the instrument, a small holder or compartment (depending on model) carries a 9V Transistor battery. The instrument cannot operate if this battery is flat. The current drain on this battery is very low and it has a very long life providing the instrument is turned OFF after use. When the battery voltage reaches 7V, the digital display will show either an arrow pointing to the left or the symbol 'LO BAT'. In either case, the 9V battery must be replaced before proceeding with the experiments.

LIGHT SOURCE (12 Volt, AC or DC. 2 amps): On the rear face of the instrument, a clear plastic lens accepts light from the 12V.AC/DC. light source supplied and directs it to the active face of the phototube. The phototube tube itself can be seen inside the housing by looking through this clear plastic lens with the aid of a small torch.

Around this lens a thick soft pad is held captive between two rails. The front rib on the body of the light source engages behind these two rails and the light source is slid down into place and will be held firmly in line with the lens. The light source is held firm so it cannot be moved out of position during the experiment and is connected by its banana plugs to any 12V.AC/DC source at about 2 amps.

Spare globes are 25W to 30W 12V QI type. **Cat: PA2043-004**

The filters, placed into the light path, cut off all wavelengths above a particular value, therefore the maximum frequency of light reaching the tube is known for the experiments dealing with Photon energy and Planck's Constant.

By removing this incandescent light source, other light sources may be used. Perhaps a mercury vapour lamp or a monochromatic light sources which emit known wavelengths. If several wavelengths are present in the light source, the filters supplied would be required to provide an upper limit of wavelength passing to the tube.

FITTING COLOUR FILTERS AND APERTURES: Two pairs of guides are fitted to the rear face of the instrument, just in front of the light source. One pair accepts the colour filters and the other pair accepts the apertures.

If a filter is inserted, the light that reaches the cell contains all the **wavelengths** that pass through the filter. If various apertures are inserted, the **amount** of light or brightness passing to the phototube is altered.

CAUTION: *It is **most important** that, during an experiment, no light other than the light through the filter reaches the phototube. Be careful that the light source is fitted properly into its mounting very close to the filters so that no other light can enter the instrument.*

If the normal light source is removed from its slide and if a different light source is to be used, take care that other light does not enter the instrument. The space between the light source and the instrument can be covered with an opaque cloth, or a piece of cardboard tube say 40mm diameter can be held between the face of the colour filter and the light source to eliminate unwanted ambient light.

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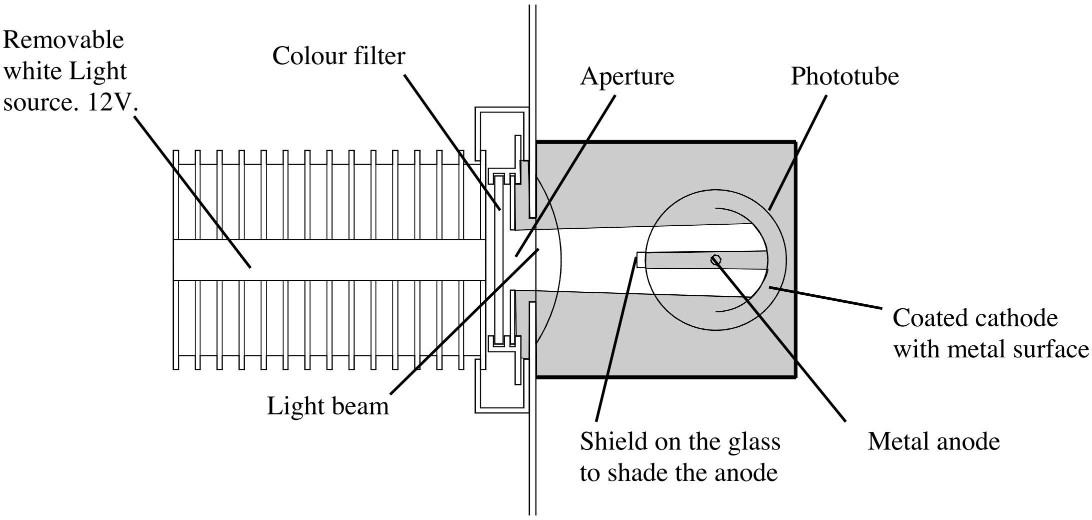
THE PHOTOTUBE:

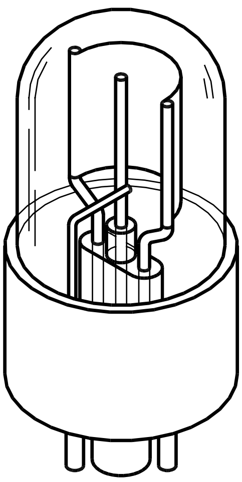
The phototube is the essential part of the instrument. It is an evacuated glass tube containing an electrode shaped like half of a cylinder. At the open mouth of this electrode, another electrode, in the form of a straight rod, is positioned at approximately the focal point of the curved surface.



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:



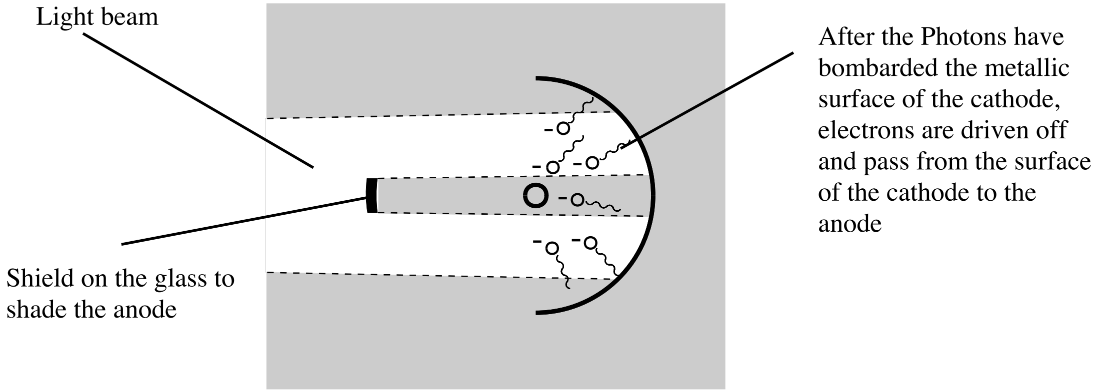
The curved surface of the cylinder is called the Cathode and is coated with a special compound that easily releases electrons when light (or photons) strike the curved surface. This coating is usually ceasium (cesium in the USA) on silver oxide.

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, we need to measure the backing voltage that stops the electrons with the highest energy.**

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. We must use the selector switch to the right of the meter to select the smallest current then read the value of the Backing Voltage when the current is at 000.0nA (at zero).

NOTE: 1 microamp is 1×10^{-6} Amp. 1 nanoamp is 1×10^{-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 select TUBE CURRENT to see the current flow and we increase the backing voltage to get exactly zero current flow at the low amps setting (0-200nA).
- When the current is at exactly zero, we select BACKING VOLTS on the switch to read the value of that backing voltage.
- We note the wavelength of the filter used and the backing voltage required for that particular wavelength. The experiment is repeated 3 times 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'.

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Notes on running the experiments: step by step:

1. Be sure the 9V battery is present in the battery holder. Switch instrument to Experiment 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. Select TUBE CURRENT on the meter switch to monitor the current through the phototube. Begin by selecting the 0-20uA range and, as this reduces almost to zero, select the very sensitive 0-200nA range. If the current exceeds 200nA, the display will show 'over-range' and if this occurs, select the microamp range again. As the backing voltage is increased and as the current through the tube reduces below 0.1 microamp, select the nA range and adjust the voltage to achieve zero amps.

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. If the current showing is over-range, select the higher current 0-20uA range. Leave the meter switch on TUBE CURRENT and increase the Backing Volts until the current (electron flow) through the tube reads close to zero microamps, then select LOW range and again adjust voltage to achieve 0.0 nanoamps through the tube.

7. Without disturbing anything, select BACKING VOLTS and observe the exact voltage 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 voltage reading.**

8. Re-select TUBE CURRENT and 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 6) to 8).

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.

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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:

- As an exercise, if a direct viewing spectrometer is available, measure the shortest wavelength passed by each filter and compare with the wavelength (in nanometres) marked on the frame of each filter.
- 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.

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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).

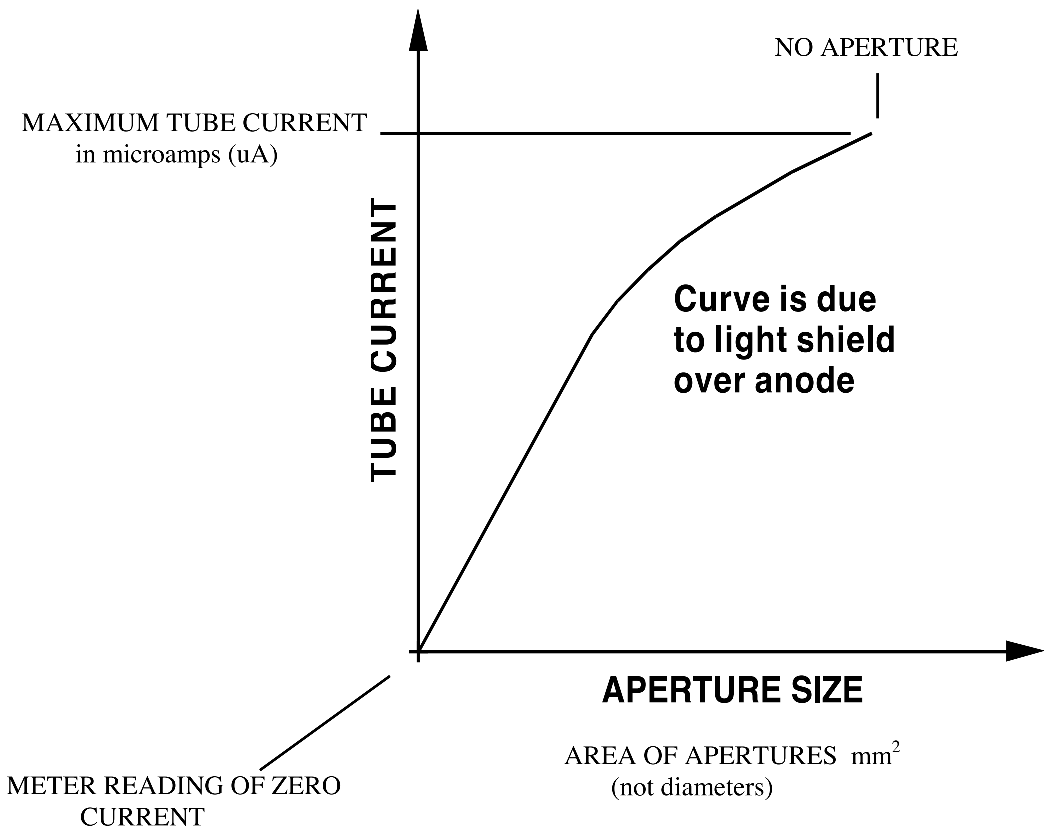
There is no voltage applied to the Phototube, but the light from the light source mounted on the rear face of the instrument will fall upon the surface of the cathode of the sensitive phototube contained within the apparatus. Electrons are excited and escape from the surface of the metallic cathode to 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 power up the instrument.**
- **Turn ADJUST knob anti-clockwise to set Backing Volts to ZERO.**
- **Set the meter switch to read TUBE CURRENT high (in microamps).**
- **Fit light source to the rails at the back of the instrument and turn light on. The meter will show 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 Voltage set to zero, select TUBE CURRENT high (microamps) and observe the phototube current altering as the different apertures are inserted into the path of the light beam. These 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.



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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 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.

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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:

$$f = 3x10^{8} / 428x10^{-9} = 7.0x10^{14} \text{ Hertz}$$

Typical tabulated results:

Filter Colour	*Shortest Wavelength*	*Freq.passed. Hz x 10^{14}*
Blue	**428 nm**	7.0
Green	**460 nm**	6.5
Yellow	**492 nm**	6.1
Orange	**530 nm**	5.7
Red	**590 nm**	5.1

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).**

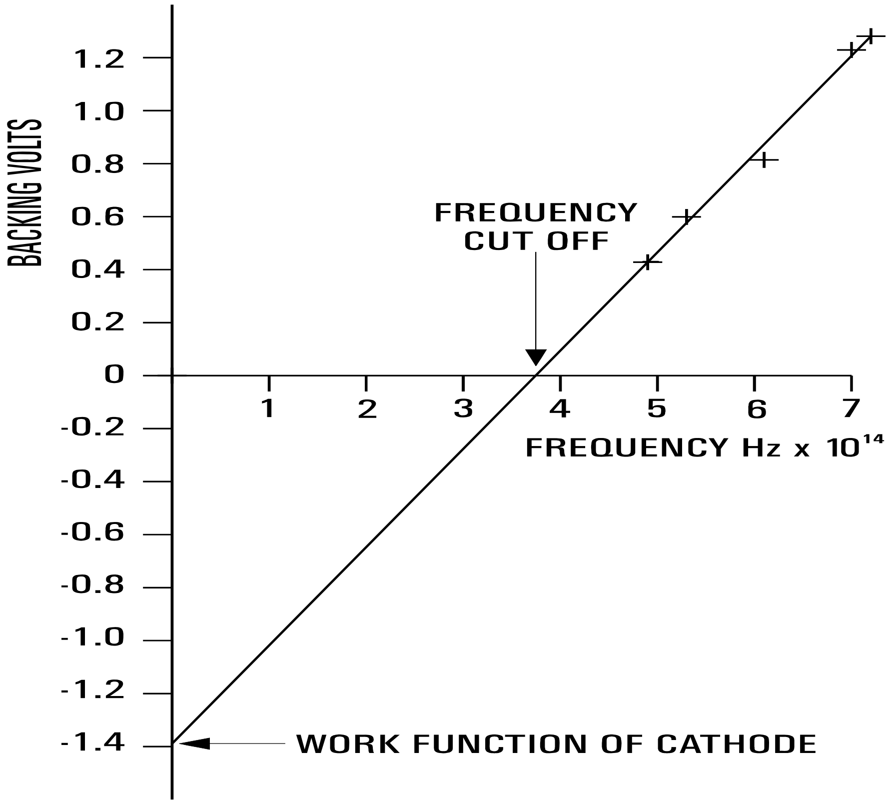
EXPERIMENT 1d: SAMPLE GRAPHS:

Typical experimental readings:

Wavelength	*Freq: Hz x 10^{14}*	*Colour*	*Backing Voltage*
428 nm	7.0	Blue	1.04 V
460 nm	6.5	Green	0.81 V
492 nm	6.1	Yellow	0.71 V
530 nm	5.7	Orange	0.55 V
590 nm	5.1	Red	0.34 V

Cut-off frequency (from the graph) = 3.7 x 10^{14} Hz.

Work function 'W' of the cathode (from the graph) = 1.4 eV.



Slope of graph = $\Delta V / \Delta f$ = 1.28/3.25 = 0.394 x 10^{-14} = h/e

Calculate 'h': (slope) x (e) = (0.394 x 10^{-14}) x (1.6 x 10^{-19}) = 6.30 x 10^{-34}

Percentage error from Planck's constant: ((6.626 - 6.30) / 6.626) x 100 = 4.9%

Depending on the exact performance and efficiency of the Photo Electric tube, errors ranging from 3 % up to 10% or even higher can be expected in calculating Planck' 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.

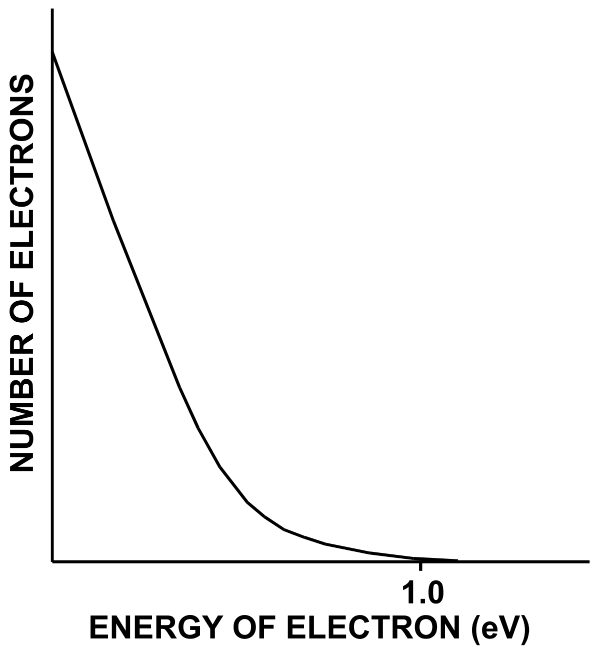
By considering the shape of the graph, deduce an energy distribution for the electrons.

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

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EXPERIMENT 2: CHARACTERISTIC CURVE OF THE PHOTO-TUBE:

CURRENT / VOLTAGE CHARACTERISTIC OF THE TUBE:

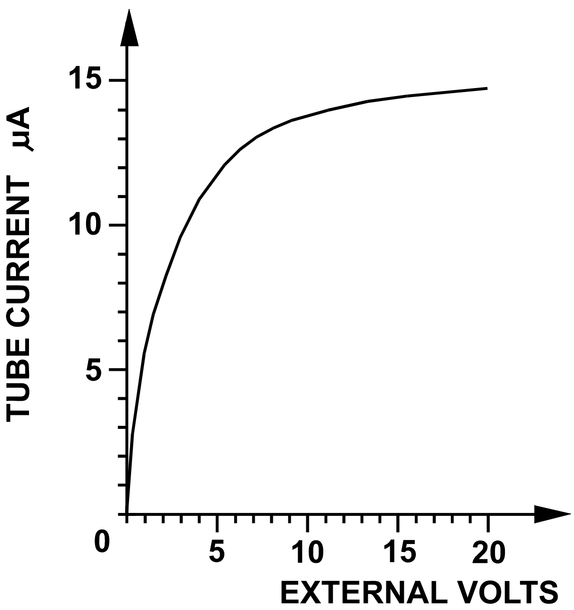
Select Experiment 2 and connect the external sockets to an adjustable power supply that can provide 0- 20V.DC. In this experiment the voltage is not a 'Backing Voltage' because in this experiment the **voltage is applied to the tube in the forward direction to encourage electron flow from the cathode to the anode.**

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 or apertures. As previously, select TUBE CURRENT high (0-20uA). 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.



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