Lab in a Box – Planck's Constant

Safety Precautions

All the signal voltages are small and harmless. The mains voltages in the mains powered equipment is dangerous but is screened in normal use.

Introduction

The development of quantum theory turned crucially on the proper understanding of the way in which electromagnetic radiation liberated electrons from the surfaces of metals.

For this experiment it is necessary to understand just a few vital points. Imagine radiation (e.g. a beam of light) falling on the surface of the metal. Then light has a particle nature (quanta) as well as the more familiar wave nature; light quanta come in discrete lumps, photons; if the frequency of the radiation is v, the energy of each photon is hv, where h is Planck's constant; the intensity of the radiation determines only the number of photons per second hitting the metal; each electron is liberated by one and only one photon.

The concept of the *work function* φ is also important. To remove an electron from the metal and leave it stationary just outside costs some energy. The smallest value of this energy for any metal sample is called the work function.

Thus if a photon of energy hv hits an electron and liberates it part of the energy will go to free the electron and the balance will result in electron kinetic energy E_{ke} For a given v the *greatest* value of E_{ke} will be

$$E_{ke} = hv - \varphi$$

If $hv < \varphi$ then no electrons can be emitted.

Now consider what happens if we put another electrode in to collect the emitted electrons. If *B* is positive with respect to *A*, all the electrons are collected. But if *B* is negative it will repel the electrons. If the negative voltage on *B* is increased, at some value V_0 all the emitted electrons are stopped and no current flows. This occurs when $eV_0 = E_{ke}$ i.e

$$eV_0 = hv - \varphi$$

There is thus a straight line relation between V_0 and v so we can perform an experiment in which these are varied and the plotted against one another. The gradient will be h/e and the intercept φ/e.

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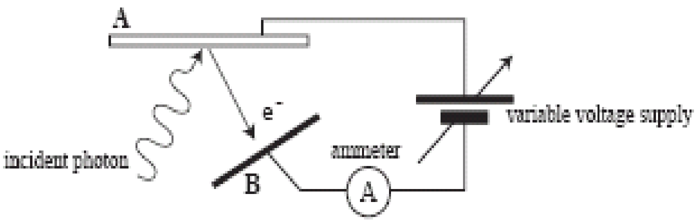

The main parts of the apparatus are contained inside a light tight box. A filament light bulb is focussed by a simple lens through a filter onto the photocell. The photocell consists of a highly evacuated tube containing the potassium metal film and a loop of platinum. The potassium metal film is connected to a metal cap at the top of the tube which in turn is connected to a very sensitive current meter. The platinum wire loop forms the other electrode of the circuit and is connected to a small screw socket on the bottom of the photocell. This allows you to apply a positive or negative bias between the loop and the metal film. Platinum is used as this metal has a very large work function.

In this experiment you will apply a negative bias (so that electrons are repelled from the platinum loop) and measure the stopping voltage V_0. Interference filters are used to provide a narrow band of frequencies to illuminate the potassium surface. These filters transmit light in a narrow wavelength band (±10 nm) around the stated wavelength and slide into the holder on the lamp housing. A microswitch operated by the filter switches on the light bulb.

Method

First, check that the circuit works correctly. Insert a filter and set the bias voltage to zero. Check that no stray light can reach the photodetector.

Turn on the lamp and you should immediately get a non-zero reading on the meter. (For sensitivity reasons, a high impedance voltmeter is used to indicate the current.)

Increase the bias voltage until the current falls to zero, i.e the bias voltage is V_0. You now have the condition $V_0 = h$

$$V_0 = \frac{h}{e}\nu - \frac{\phi}{e}$$

Increase the bias voltage a bit more and the current goes negative (our simple theory predicts that there should be no current!).

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Measure V_0 for 6–7 filters sufficient to span the wavelength range 400 to 700 nm. Obtain an estimate of the uncertainty in V_0 by repeating a measurement at *one* wavelength 2 or 3 times.

Plot a graph of V_0 against ν (not wavelength!) and draw the uncertainties in V_0 and the filter bandwidth as 'error bars'.

Question

Are your points consistent with a straight line? If not, why not?

In any case find h/e from the slope and estimate φ from the intercept. Estimate the uncertainties

in h/e and φ. Compare your result with the book value of h/e = 4.14×10^{-15} JsC^{-1}?

Question

- Is there evidence for any systematic error?
- Do you think that the reverse photocurrent affects the measurement?
- What do you think is the origin of this current?
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Wavelength of filter /m	**Frequency of light / Hz**	**Stopping Voltage /V**

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Risk Assessment

Task: SUPI event – Laboratory demonstrations of measuring Planck's Constant			
Department	Physics	Assessment ID	
Assessor	Phil Furneaux	Date of assessment	20-10-16
Authorised by		Review date	

Step 1 List significant hazards	**Step 2** who might be harmed	**Step 3** determine appropriate controls	**Step 4** make it happen
Electric shock From the plug to the power supply	Person setting up experiment	Do not turn on plug switch until plus is safely plugged into socket	procedure
Damage to equipment		The apparatus will only be used under supervision of a demonstrator	supervision
Damage from UV radiation	experimenter	The UV light source is shut off with a shutter which is opened automatically when a filter is placed in the slot in front photodiode. Students instructed not to look into the UV light.	procedure