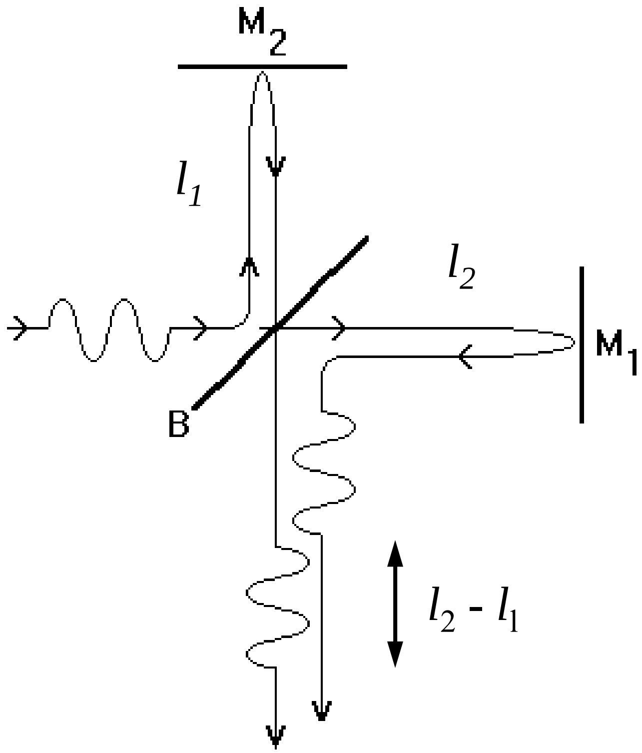
The Michelson Interferometer

The <u>interferometer</u> measures the coherence of light by making the light "interfere" with itself.
A beam of light is passed through a partially transparent mirror, or "beamsplitter",
so that every train of waves in the beam is split into two identical trains.
Each wave train is sent along a separate path, after which the waves are again combined.



<u>destructive interference</u>

the eye will see darkness if $|l_2 - l_1| = (n + 1/2)\lambda_0$

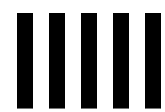
and a bright light if $|l_2 - l_1| = n\lambda_0$

<u>constructive interference</u>

for a long coherence length $\Delta\chi > |l_2 - l_1|$

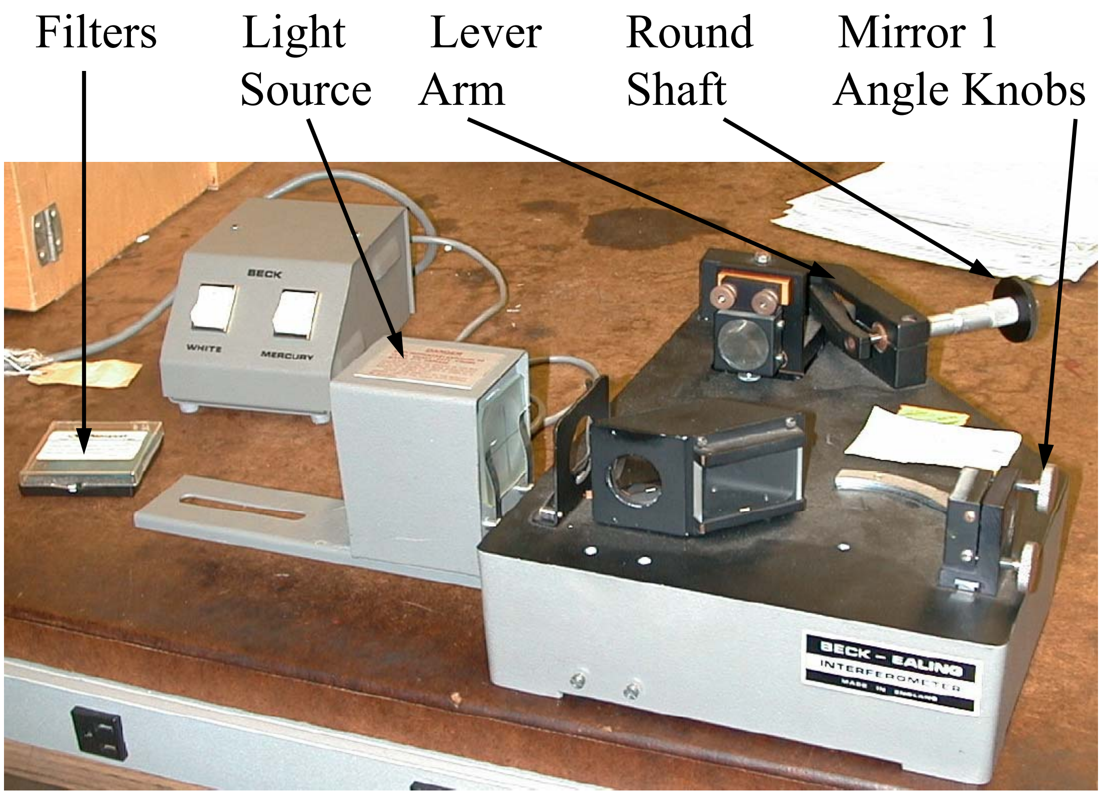
for a short coherence length $\Delta\chi < |l_2 - l_1|$
one portion of the packet is delayed enough so that it
fails to overlap its partner at the output, and
<u>no interference can occur</u>

Each mirror has some angular deviation from perpendicularity. Thus, l_2 - l_1 varies
from one point on the mirror to another → a system of oriented stripes, or "fringes"



<u>Measuring coherence length:</u> begin with $l_1 = l_2$, and increase l_2 until the <u>interference fringes</u>
become weaker and just disappear. l_2 - l_1 is then the coherence length $\Delta\chi$.

The experiment



The apparatus:

The micrometer reading that gives l_2 - $l_1 = 0$ is marked on the base of the instrument

1 mm (dial) = 400 μm (Δl)

A <u>white bulb</u> emits at all visible wavelengths.
A <u>mercury vapor bulb</u> emits light at a few discrete wavelengths. Refer to the Spectral Lines table.

Procedure:

- Determine $\Delta\lambda$ for the single green line of Mercury

1. Adjust the angle of Mirror M1: Set about 10 fringes in the field of view
2. Estimate λ_0 from the fringe motion versus dial tics
3. Place an upper limit on $\Delta\lambda$ for the mercury green line by seeing how large l_2 - l_1 can be made with the fringes still visible

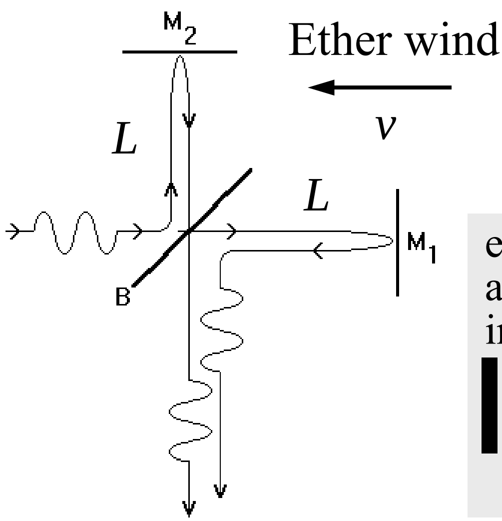
- Determine $\Delta\lambda$ for white light

1. Adjust $l_2 - l_1 \approx 0$, and then search for fringes
2. Determine how large l_2 - l_1 can be with the fringes still visible

- Determine $\Delta\lambda$ for the green and blue filters acting on white light

the Michelson-Morley experiment (1887)

ether – a medium
in which light waves could travel



expected fringe shift after a rotation of the interferometer by 90^0

one of the arms was aligned along the direction of the motion of the Earth through the ether

the interferometer was rotated by 90^0
→ no fringe shift was observed!

the speed of light does not depend on the direction of light propagation

the idea of an ether became unnecessary

special relativity, Einstein (1905)

$$t_1 = \frac{L}{c+v} + \frac{L}{c-v} = \frac{2L}{c}\left(1-\frac{v^2}{c^2}\right)^{-1}$$

time to travel arm 1

$$t_2 = \frac{2L}{\left(c^2-v^2\right)^{1/2}} = \frac{2L}{c}\left(1-\frac{v^2}{c^2}\right)^{-1/2}$$

time to travel arm 2

$$\Delta t = t_1 - t_2 = \frac{2L}{c}\left[\left(1-\frac{v^2}{c^2}\right)^{-1} - \left(1-\frac{v^2}{c^2}\right)^{-1/2}\right] \approx \frac{Lv^2}{c^3}$$

$$\Delta d = c\left(2\Delta t\right) = \frac{2Lv^2}{c^2}$$

rotating by 90^0 → path difference Δd corresponding to Δt

$$\text{Shift} = \frac{\Delta d}{\lambda} = \frac{2Lv^2}{\lambda c^2}$$

corresponding fringe shift (a change in path of 1 λ → a shift of 1 fringe)

$$\Delta d = \frac{2\left(11m\right)\left(3\times10^4 m/s\right)^2}{\left(3\times10^8 m/s\right)^2} = 2.2\times10^{-7} m$$

$$\text{Shift} = \frac{\Delta d}{\lambda} = \frac{2.2\times10^{-7} m}{5.0\times10^{-7} m} \approx 0.4$$

EXPERIMENT #3
The Photoelectric Effect

GOALS

Physics

Measure Planck's constant by using the photoelectric effect.

Errors

Estimate the range of “allowable” slope fits to your data points to estimate the accuracy of your determination of *h*. Compare your value of *h* to the accepted value.

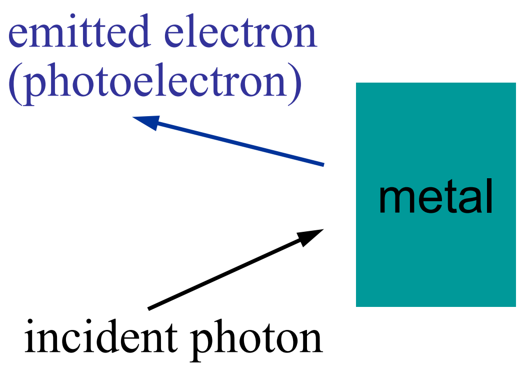
$$h = 6.63\times10^{-34}\ \mathrm{J\cdot s}$$
$$= 4.14\times10^{-15}\ \mathrm{eV\cdot s}$$

References

Serway, Moses, Moyer §3.4

photoelectric effect is the ejection of electrons from matter by incident electro-magnetic radiation, particularly by visible light, ultra-violet light, and x-rays

$E = hf$	energy of a photon of frequency *f* *h* is Planck's constant
W_0	the work function of the metal
$KE = \frac{1}{2}mv^2$	electron kinetic energy
$hf = W_0 + KE$	Einstein relation (1905)



you will measure *KE* versus *f*, thus determining *h* experiment by Philip Lenard (1902)

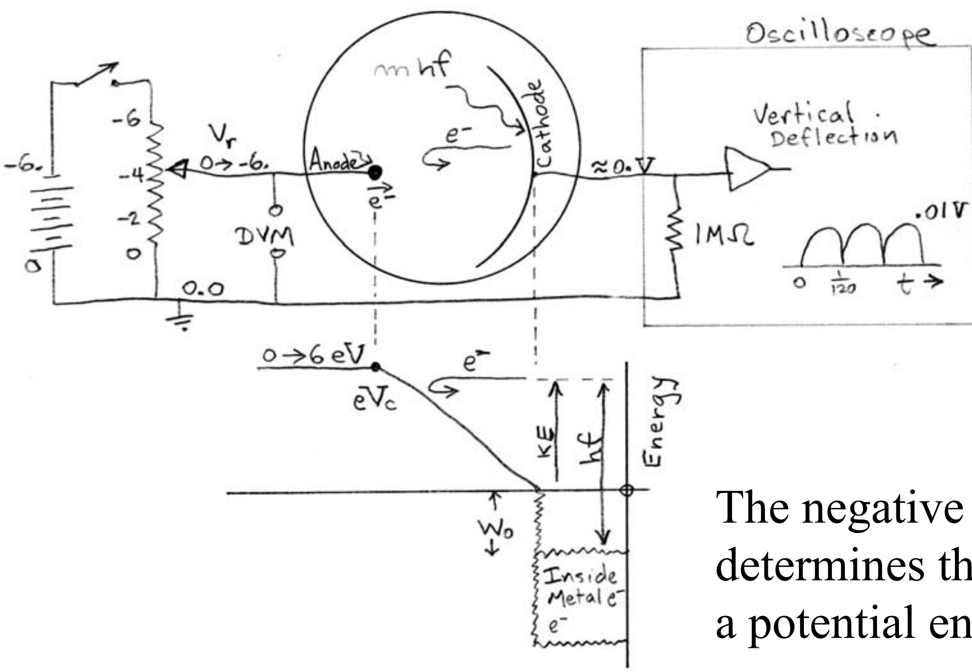
Equipment

$$hf = W_0 + KE$$

1. Mercury discharge lamp
2. Set of light filters
3. Photosensitive vacuum tube
4. Circuit to produce retarding voltage across phototube
5. Oscilloscope

Principle of the experiment:

1. A photon impinging on the cathode ejects an electron
2. If $KE < eV_r$ the emitted electron returns to the cathode $\rightarrow$ no cathode photocurrent;
If $KE > eV_r$ the emitted electron reaches the anode $\rightarrow$ cathode photocurrent (developing the voltage across the 1MΩ resistor)
3. The cathode photocurrent goes to zero when $KE = eV_c$



$$hf = W_0 + eV_c \rightarrow h = \frac{d(eV_c)}{df}$$

Measuring V_c as a function of $f \rightarrow$ finding h

The negative "retarding" voltage $-V_r$ applied to the anode determines the height of the potential hill. V_r= - 1.0 V gives a potential energy hill of $PE = 1.6 \times 10^{-19}\,\text{J} = 1\text{eV}$

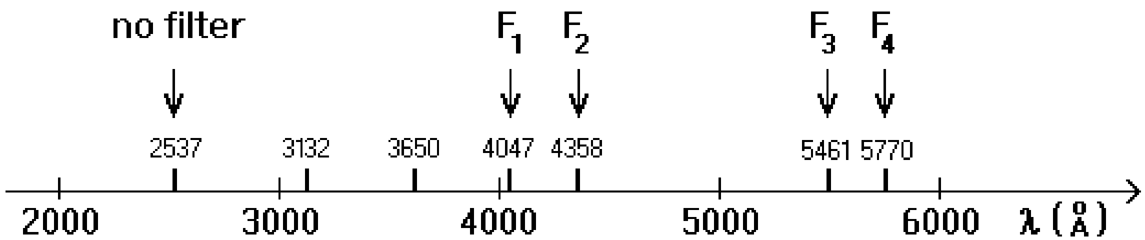
A voltage divider allows retarding potentials $V_r = 0 \rightarrow -6\text{ V}$

Start the light source by setting the toggle switch to start and pressing the red start button; then the toggle switch must be set to operate, or else the life of the discharge tube will be greatly reduced.

DO NOT LOOK DIRECTLY INTO THE DISCHARGE TUBE WHEN THE LAMP IS OPERATING since ultra violet radiation damages the unprotected eye.

Place the light source and phototube housing an inch or so apart and cover both with the light shield hood to keep the room light out of the phototube.

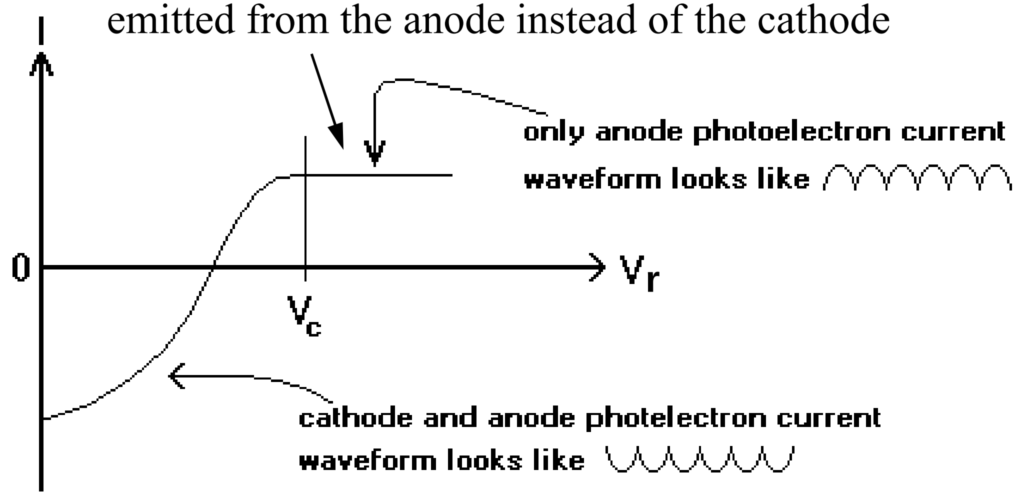
Turn off the battery switch when you are through with the measurements.



The light source is a mercury discharge lamp.
The arrows indicate the λ that are passed by 4 special filters.

The mercury lamp intensity peaks 120 times per second → photocurrent also peaks at 120 Hz.

Side effect of the experiment: Photoelectrons emitted from the anode instead of the cathode



The anode electrons are accelerated by V_r and lead to nearly constant electron current at any V_r
Direction of the anode photocurrent is opposite to that of the cathode photocurrent.

The anode photocurrent shifts up the total photocurrent $I=I_{anode}-I_{cathode}$
Therefore, $V_r=V_c$ when I=const (not when I=0)

Basic lab measurements

- Measure the cathode electron cutoff voltage V_c
(by each student separately)
for each of the four filters, and also for no filter.

- Make about 4 determinations of the cutoff voltage V_c
for each filter to get an idea of experimental error.

- Calculate the highest frequency present in the light
for each filter *f* and plot your V_c as a function of *f*.
Each data point should have error bars indicating
the estimated precision of your measurement of V_c.

- Draw an average straight line through your data and
from this line determine Planck's constant.
The uncertainty in your result can be obtained by
noting the range of different lines you can draw
through your data.

- Compare *h* with the commonly accepted value