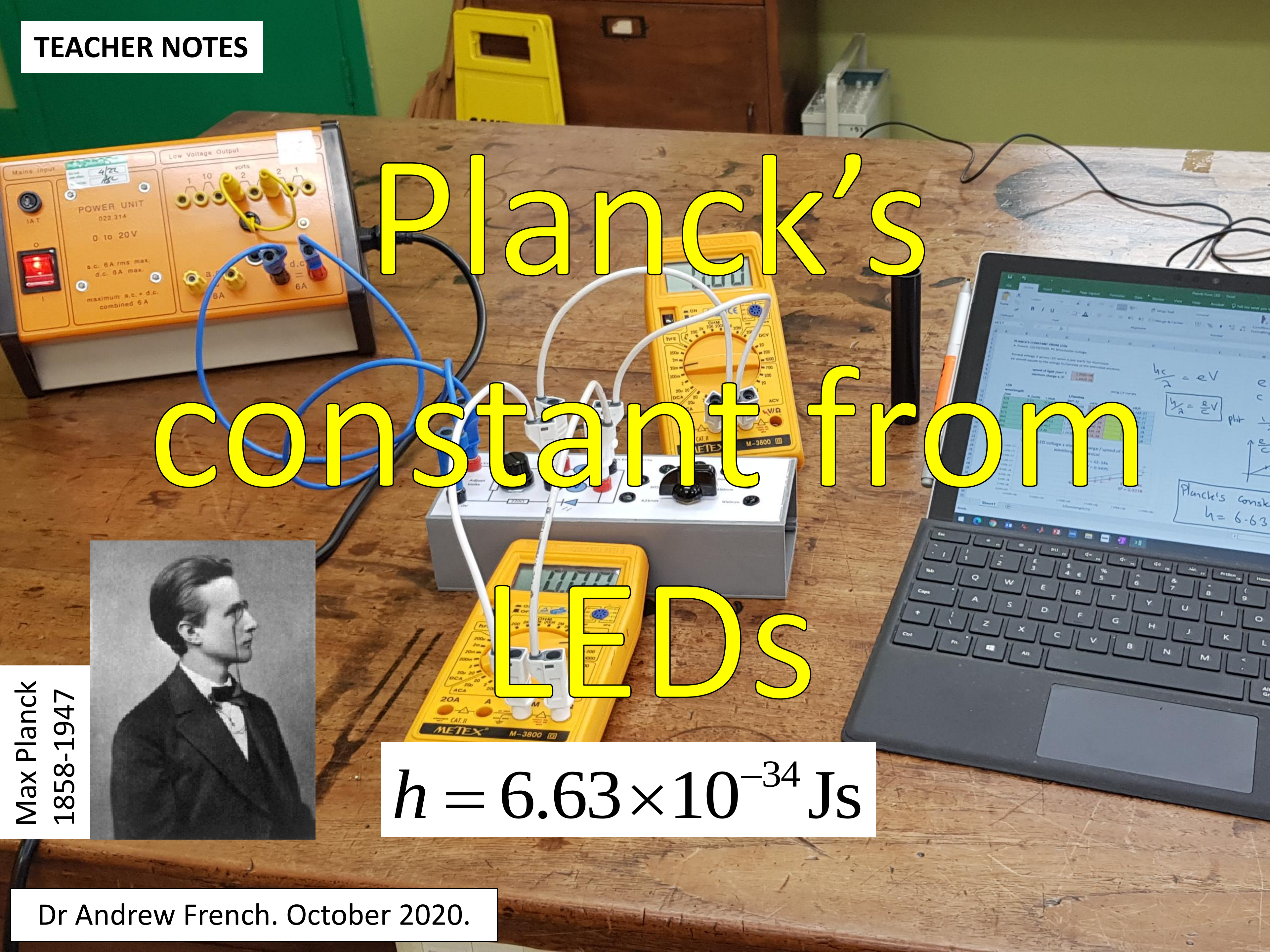
TEACHER NOTES

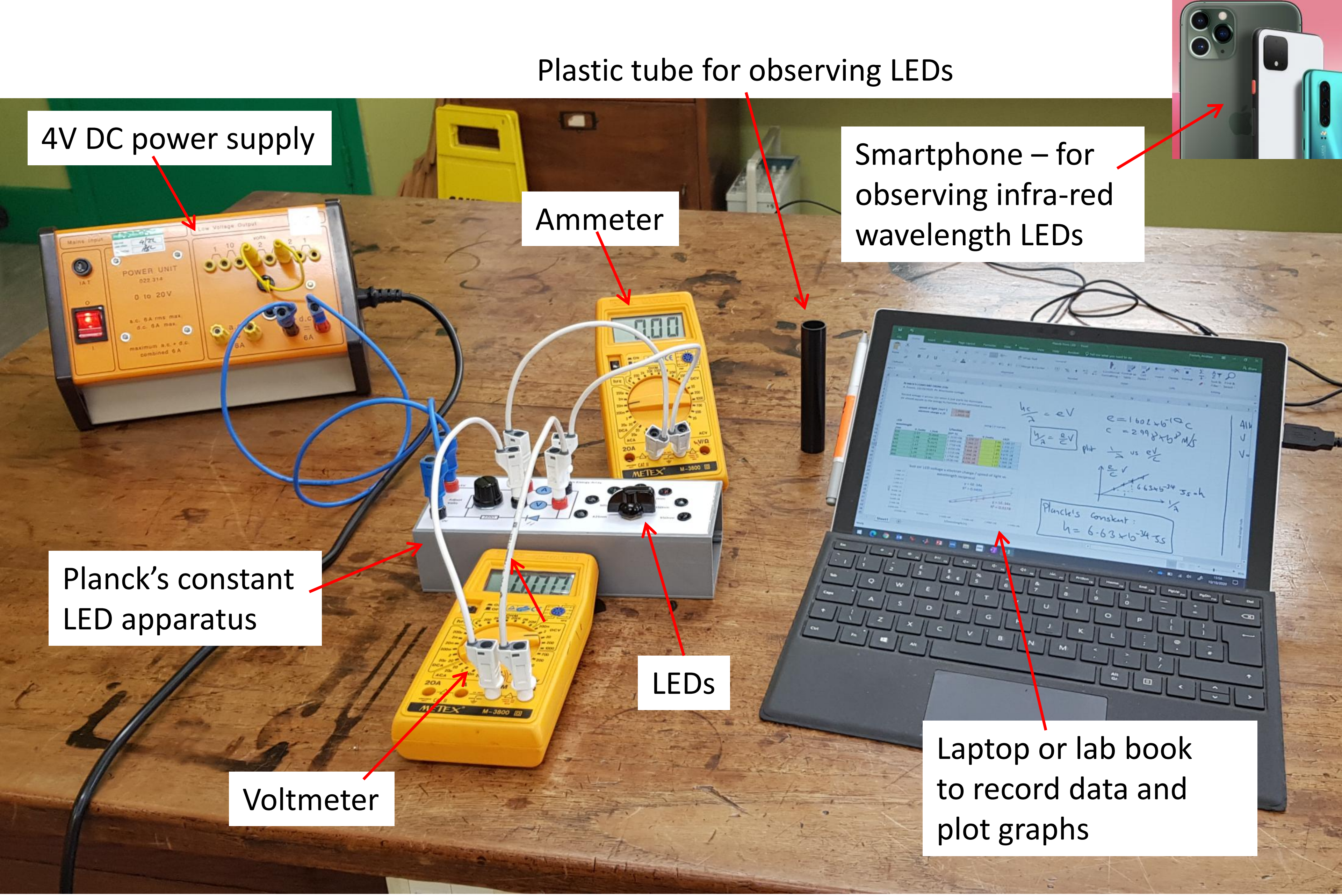
Planck's constant from LEDs



$$h = 6.63 \times 10^{-34}\ \mathrm{Js}$$

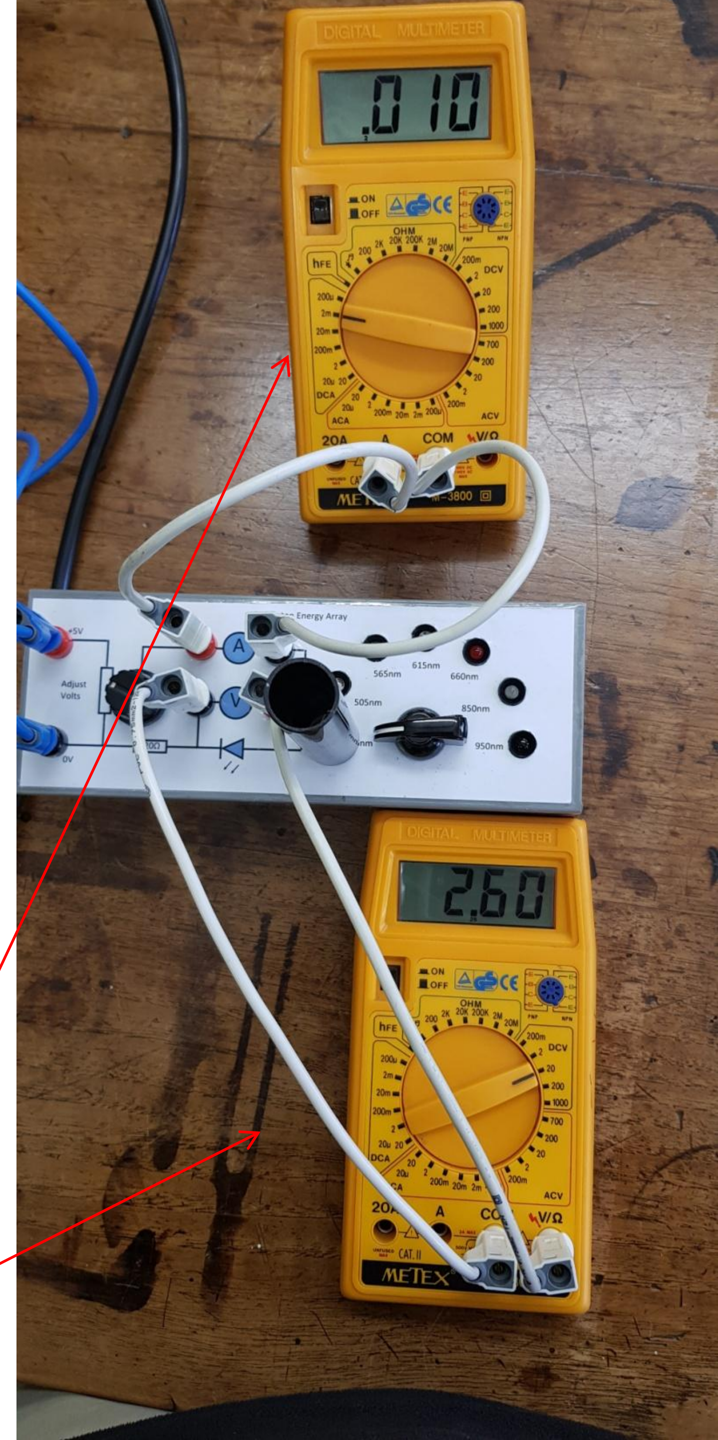
Max Planck
1858-1947

Dr Andrew French. October 2020.



Equipment setup


Photon Energy Array
+5V
Adjust
Volts
0V
A
V
220Ω
565nm
615nm
660nm
505nm
850nm
425nm
950nm
Light Emitting Diodes (LEDs) Wavelengths 425nm (purple) to 950nm (Infra Red)
Potentiometer to vary voltage across LED
Plastic tube for observing LEDs when ‘just on’



Don’t use more than 4V for the power supply – the maximum input to the Planck’s Constant LED apparatus is 5V.

Ammeter scale will be mA
Voltmeter scale will be 0 to 2 and then 2 to 20V

The LED (light emitting diode) is a *semiconductor*, with **electron energy levels** that are separated by an amount that corresponds to the **energy of photons in the visible and infra-red spectrum.**

If the photon energy is: $$E = \frac{hc}{\lambda}$$

wavelength /m

$c = 2.998 \times 10^{8}\,\mathrm{ms^{-1}}$ speed of light

$h = 6.63 \times 10^{-34}\,\mathrm{Js}$ Planck's constant

then photons will only be released from the LED when the applied voltage V multiplied by the charge on the electron e exceeds E.

Therefore expect *no light* from the LED (and no current in the ammeter) until:

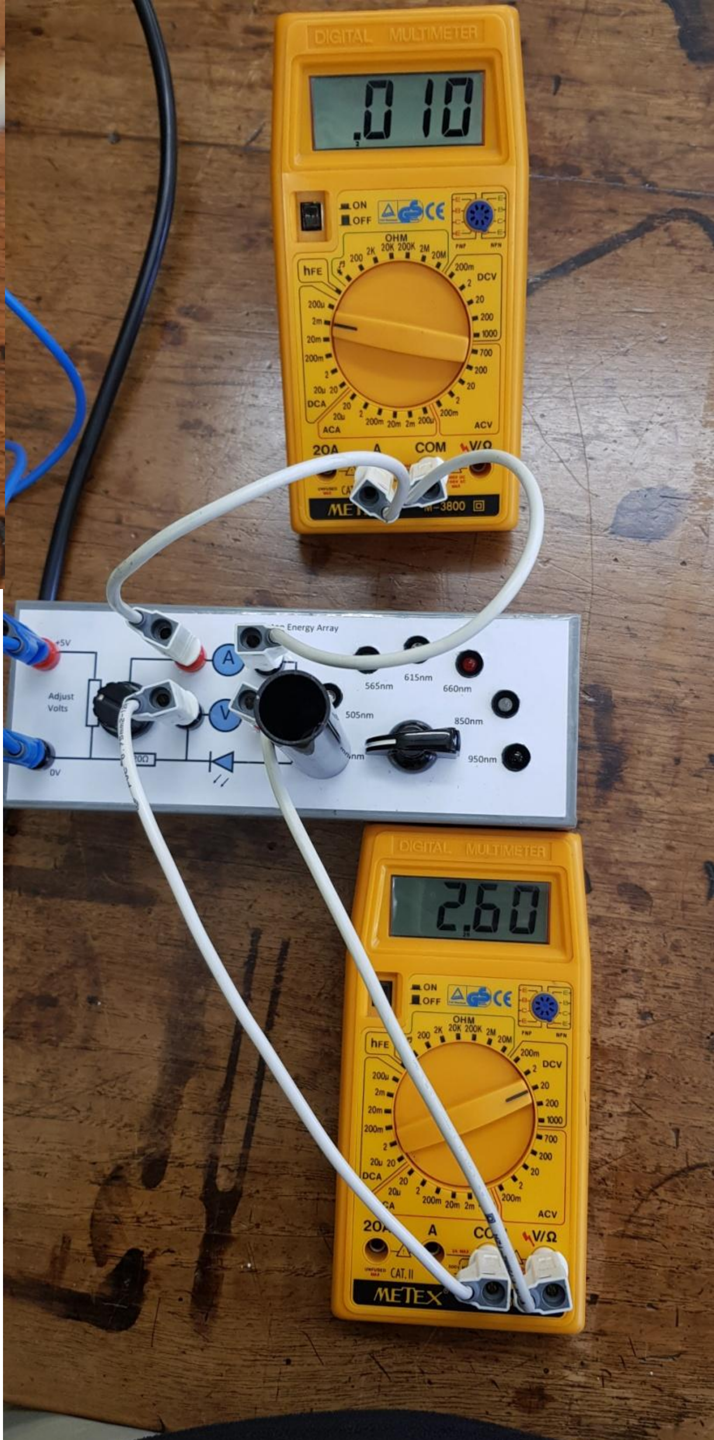
$$V \geq \frac{hc}{e\lambda}$$

$e = 1.602 \times 10^{-19}\,\mathrm{C}$

electron charge

TASK1:

- Set up equipment and turn potentiometer fully anti-clockwise. This will correspond to maximum resistance and therefore minimum voltage across the LED.
- Choose an LED using the switch. Write down the wavelength in nm.
- Gradually reduce the potentiometer resistance until the LED begins to lights up. Observe it using the plastic tube.
- Record the voltage that this occurs.



When the LED 'just starts to illuminate' $\dfrac{eV}{c} = \dfrac{h}{\lambda}$ So plotting $\dfrac{eV}{c}$ vs $\dfrac{1}{\lambda}$ should yield a **straight line graph from the origin**, the gradient of which is Planck's constant h.

In the example below, this is the red line of best fit, yielding $h = 5.41 \times 10^{-34}\,\mathrm{Js}$ which is about 18% different from the actual value.

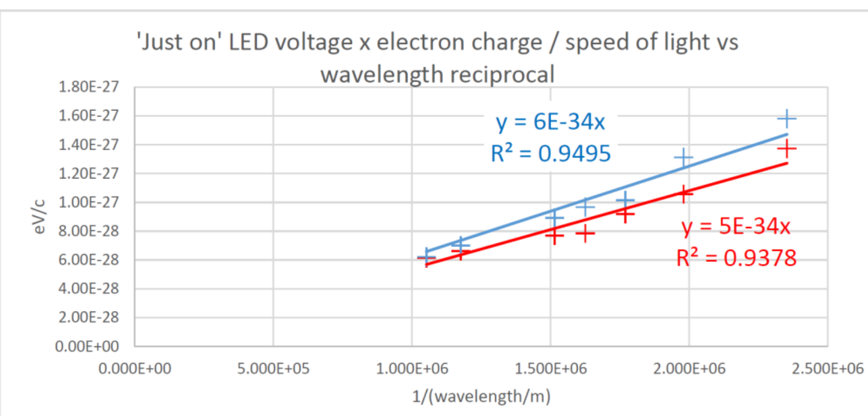
PLANCK'S CONSTANT FROM LEDs

A. French. 10/10/2020. P5 Winchester College.

Record voltage V across LED when it just starts for illuminate.
eV should equate to the energy hc/lambda of the emmitted photons.

speed of light /ms^-1	2.998E+08
electron charge e /C	1.602E-19

LED wavelength /nm	**V /volts**	**I /mA**	**1/lambda (m^-1)**	**eV/c**	using I,V curves **V /volts**	**eV/c**
425	2.57	0.0065	2.353E+06	1.37E-27	2.96	1.58E-27
505	1.98	0.0003	1.980E+06	1.06E-27	2.46	1.31E-27
565	1.72	0.0375	1.770E+06	9.19E-28	1.90	1.02E-27
615	1.47	0.0003	1.626E+06	7.86E-28	1.81	9.67E-28
660	1.44	0.0073	1.515E+06	7.69E-28	1.67	8.92E-28
850	1.24	0.457	1.176E+06	6.63E-28	1.31	7.00E-28
950	1.15	3.35	1.053E+06	6.15E-28	1.17	6.23E-28



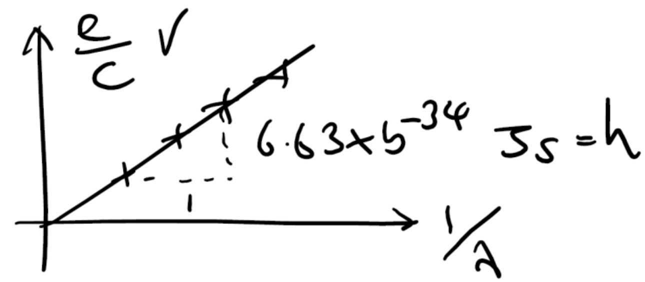
$\dfrac{hc}{\lambda} = eV$

$e = 1.602 \times 10^{-19}\,\mathrm{C}$

$c = 2.998 \times 10^{8}\,\mathrm{m/s}$

$\boxed{h/\lambda = \dfrac{e}{c}V}$

plot $\dfrac{1}{\lambda}$ vs eV/c



$\boxed{\text{Planck's constant: } h = 6.63 \times 10^{-34}\,\mathrm{Js}}$

We can use the same equipment to determine a much more accurate value of Planck's constant by recording the **voltage vs current curves** for each LED.

Extrapolate the linear region to zero current, and take this as the voltage corresponding to:

$$V = \frac{hc}{e\lambda}$$

Then plot $\dfrac{eV}{c}$ vs $\dfrac{1}{\lambda}$ as before.

LED wavelength /nm	V0 /volts
425	2.96
V /volts	I /mA
2.97	1.04
3.06	2.07
3.12	3.09
3.16	4.01
3.21	5.10
3.23	5.70
3.27	7.06
2.85	0.32
2.90	0.58
2.93	0.75
3.00	1.34
3.08	2.45
3.14	3.53
3.18	4.55

LED wavelength /nm	V0 /volts
505	2.46
V /volts	I /mA
2.47	1.04
2.54	2.01
2.60	3.00
2.64	4.04
2.68	5.03
2.73	6.24
2.75	7.12
2.79	8.33
2.81	9.05
2.81	9.15
2.61	3.45
2.69	5.32
2.71	5.95
2.57	2.47

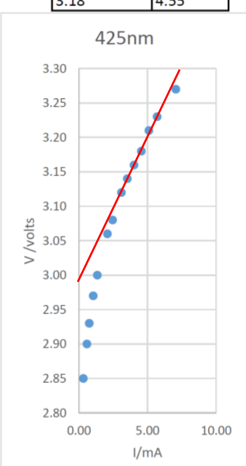
LED wavelength /nm	V0 /volts
565	1.9
V /volts	I /mA
1.86	1.09
1.89	2.02
1.91	3.02
1.94	4.13
1.95	5.14
1.97	6.15
1.98	7.14
2.00	8.24
2.01	9.11
2.02	10.08
2.04	11.74
2.04	12.15
2.05	12.44
2.04	11.94

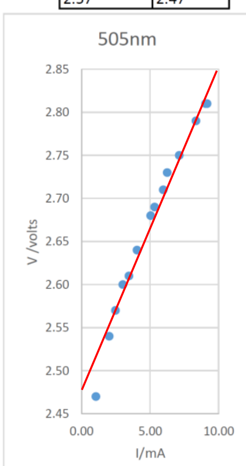
LED wavelength /nm	V0 /volts
615	1.81
V /volts	I /mA
1.80	1.06
1.83	2.07
1.86	3.00
1.88	4.05
1.90	5.09
1.92	6.06
1.94	7.11
1.96	8.04
1.98	9.18
1.99	10.19
1.85	3.31
1.83	2.67
1.82	1.86
1.78	0.79

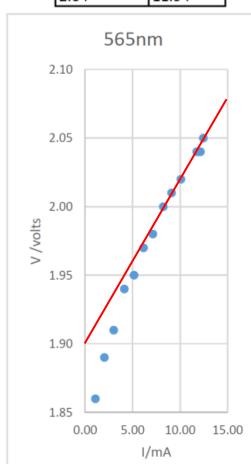
LED waveleng th /nm	V0 /volts
660	1.67
V /volts	I /mA
1.65	1.04
1.68	2.09
1.70	3.11
1.72	4.24
1.74	5.32
1.76	6.63
1.77	7.55
1.78	8.51
1.79	9.12
1.80	9.85
1.81	10.67
1.83	12.54
1.84	13.08
1.84	13.13

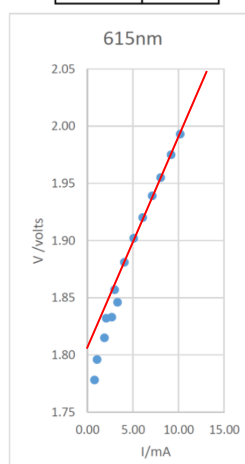
LED wavelength /nm	V0 /volts
850	1.31
V /volts	I /mA
1.27	1.04
1.30	2.07
1.31	3.09
1.32	3.99
1.33	5.01
1.34	6.12
1.35	7.03
1.35	8.05
1.36	9.24
1.36	10.33
1.37	11.13
1.37	12.41
1.38	14.69
1.38	15.06

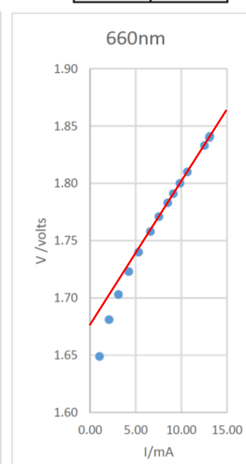
LED wavelength /nm	V0 /volts
950	1.165
V /volts	I /mA
1.11	0.95
1.14	1.99
1.16	3.04
1.17	4.03
1.18	5.03
1.18	6.08
1.19	7.09
1.20	8.19
1.20	9.20
1.21	10.09
1.21	11.34
1.22	12.49
1.22	13.13
1.23	14.93

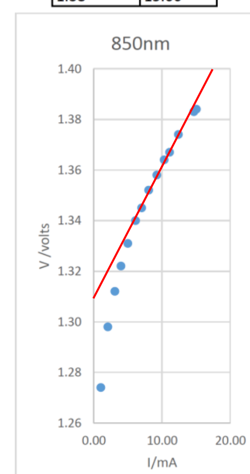


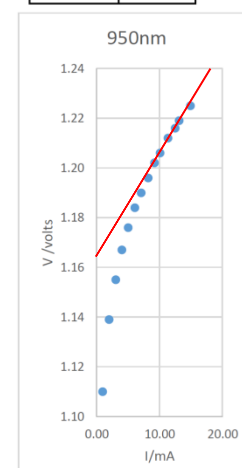












Voltages using I,V curve extrapolation

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					using I,V curves	
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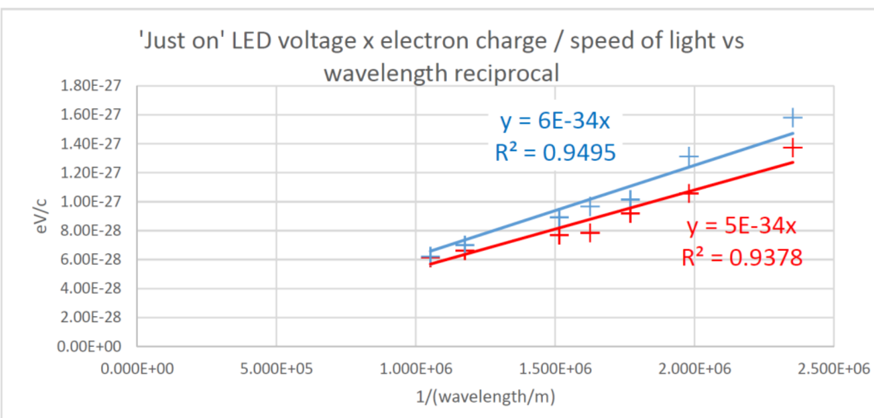

$$\frac{hc}{\lambda} = eV$$

$e = 1.602\times10^{-19}$ C

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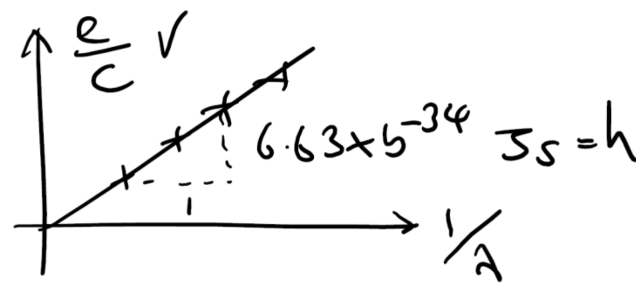
$$\boxed{\frac{h}{\lambda} = \frac{e}{c}V}$$

plot $\frac{1}{\lambda}$ vs $\frac{eV}{c}$



Planck's constant:

$h = 6.63\times10^{-34}$ Js

In this case the gradient of the graph is: $h = 6.26\times10^{-34}\,\mathrm{Js}$

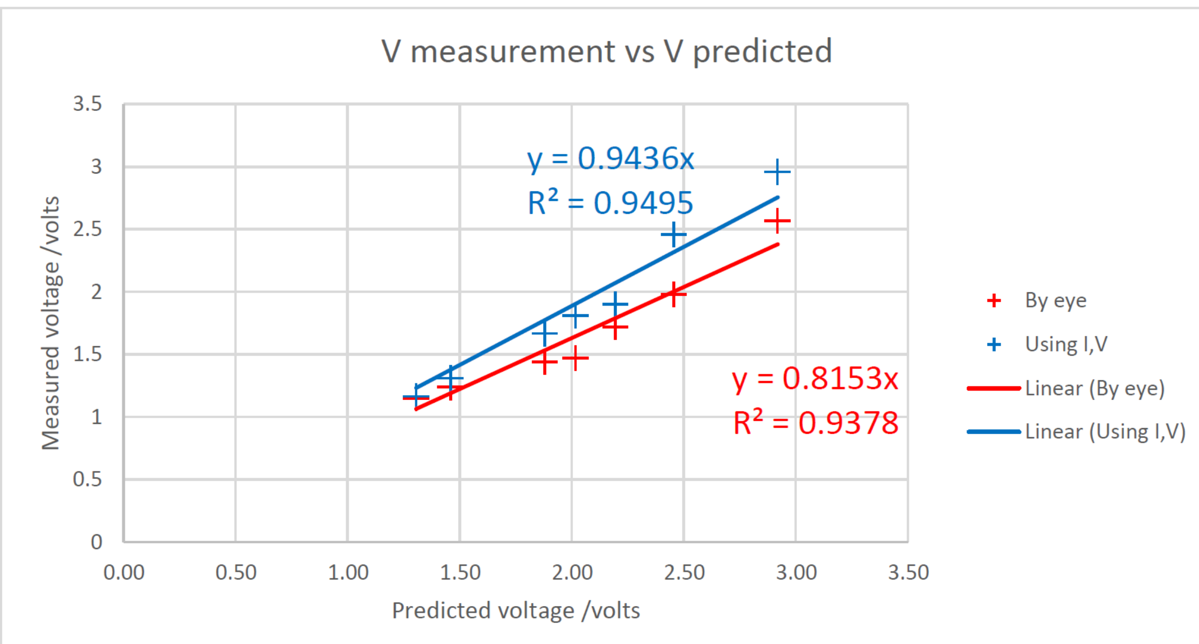
Alternative is to plot
V vs $V_{predicted}$

$$V = \frac{hc}{\lambda e}$$

hc/*lambda*e)
2.92
2.46
2.20
2.02
1.88
1.46
1.31

So measured h is:

By eye:	5.41E-34
Using I,V:	6.26E-34



This plot of predicted vs measured voltages is perhaps a more obvious contrast between model and measurement. Ideally the graphs should be $y = x$ for a perfect correlation. You can clearly see the I,V curve method results in better agreement than the 'by eye' method.