UNSW School of Computer Science and Engineering

Predict Stock Movements Using News

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Question 1 - Photoelectric Experiment

Q1 Part a - Planck's constant

If the stopping potential is U, the frequency f and the work function of sodium ϕ then we know, from Einstein, that

$$U = hf - \phi$$
$$U = \frac{hc}{\lambda} - \phi$$

Let the stopping potential and wavelengths for the $300nm$ and $400nm$ experiments be U_1, λ_1, U_2 and λ_2 respectively. Then we can simultaneously solve for h:

$$U_1 = \frac{hc}{\lambda_1} - \phi \tag{1}$$
$$U_2 = \frac{hc}{\lambda_2} - \phi \tag{2}$$

Subtracting (2) from (1) we find:

$$
\begin{aligned}
U_1 - U_2 &= hc\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right) \\
h &= \frac{U_1 - U_2}{c\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)} \\
&= 4.1 \times 10^{-15} eVs \\
&= 6.6 \times 10^{-34} Js
\end{aligned}
$$

Where, of course, all values are rounded to 2 significant figures. This is the correct value (The accepted value is $6.626 \times 10^{-34} eVs$).

Q1 Part b - Work function

We can find ϕ by simply substituting the value for h in (1):

$$
\begin{aligned}
\phi &= \frac{hc}{\lambda_1} - U_1 \\
&= 2.3eV
\end{aligned}
$$

This is the correct value of ϕ for sodium, as the accepted value is $2.28eV$ [2].

Q1 Part c - Threshold wavelength

The cutoff wavelength λ can now be calculated by:

$$
\begin{aligned}
0 &= \frac{hc}{\lambda} - \phi \\
\lambda &= \frac{hc}{\phi} \\
&= 540nm
\end{aligned}
$$

This is extremely close to the value if derived from previously mentioned accepted values, $\lambda = 546.6nm$.

QUESTION 2 - SINGLY IONISED HELIUM

According to the derivation of the Bohr model, the total energy of an electron in the n^{th} shell is given by

$$E_n = -E_0 \frac{Z^2}{n^2}$$

Where E_0 was $13.6eV$, and "0" energy is an electron not moving, infinitely far from the nucleus. Importantly, Z is the atomic number of the atom - so for Helium, $Z = 2$. Thus we find the energy of an electron in the nth shell of a singly-ionised Helium atom as

$$E_n = -\frac{54.4}{n^2} eV$$

We can therefore calculate the frequency $f = \frac{\Delta E}{h}$ and wavelength $\lambda = \frac{c}{f}$ of the emission lines of singly-ionised Helium as compared to Hydrogen:

Table 1: Helium

From	To	Energy (eV)	Wavelength (nm)
4	3	2.64	469
6	4	1.89	657
7	4	2.29	542
8	4	2.55	487
9	4	2.73	455
11	5	1.73	719
12	5	1.8	690
13	5	1.85	669
∞	5	2.18	570

Table 2: Hydrogen

From	To	Energy (eV)	Wavelength (nm)
3	2	1.89	657
4	2	2.55	487
5	2	2.86	434
6	2	3.02	411
7	2	3.12	397

Note that only those wavelengths in the visible range have been presented here. To see a more complete list of wavelengths, see Appendix 1.

From these values, and noting that the visible wavelength range is $400-700nm$ or so, we can see that Singly-Ionised Helium would have many more visible emission lines than Hydrogen. More importantly, the series of emission lines going to $n=5$ approaches a visible wavelength, $570nm$. This would be quite faint, as very few electrons would be in shells $n>10$, but if the Helium were very hot then this series of lines would visibly seem to be approaching the limit $\lambda = 570nm$.

Question 3 - Properties of a free electron

The given wavefunction is:

$$\psi(x,t) = \sin(kx - \omega t)$$

We know that this function must be periodic in x, specifically completing a period every λ that x changes. This means that, with the given value of k:

$$\begin{aligned} k(x+\lambda) &= kx + 2\pi \\ \lambda &= \frac{2\pi}{k} \\ \lambda &= 0.13nm \end{aligned}$$

Momentum is given by DeBroglie's Equation:

$$\begin{aligned} p &= \frac{h}{\lambda} \\ p &= 5.3 \times 10^{-24} kgms^{-1} \end{aligned}$$

Kinetic Energy is found by the usual formula, where $p = mv$:

$$\begin{aligned} E &= \frac{1}{2}mv^2 \\ &= \frac{1}{2}\frac{p^2}{m_e} \\ &= 1.5 \times 10^{-17} J \end{aligned}$$

Finally, speed is magnitude of velocity, and the velocity is only one-dimensional (as the wavefunction only has one space variable) so

$$\begin{aligned} |v| &= |\frac{p}{m_e}| \\ &= 5.8 \times 10^{6} ms^{-1} \end{aligned}$$

QUESTION 4 - DETECTION OF LASER LIGHT

Q4 PART A - SEMICONDUCTOR MATERIALS

This photon would have and energy of:

$$\begin{aligned} E &= hf \\ &= \frac{hc}{\lambda} \\ &= 2.48eV \end{aligned}$$

The photon must be able to give all of its energy to a single electron in the valence band. As this electron must jump up by the *band gap energy or more*, the band gap energy must be less than or equal to the photon's energy.
The only material that satisfies this is material A. Material B and C would not absorb the photon, as there is not enough energy to excite an electron to the conduction band.

Material B is actually an insulator, as any material with a band gap $> 3.5eV$ is considered an insulator [1]; in fact, it is one of the best insulators (The best known insulator is diamond with the same band gap of $6eV$ [1]). Material C is an unbelievably good insulator, one and a half orders of magnitude better than the best insulator we know.

Q4 PART B - PHOTOELECTRIC EFFECT

The photoelectric effect could definitely be used to detect this light - with no backing voltage, electrons would jump off the cathode and produce a current. However, one must consider Einstein's equation for kinetic energy of the electrons E, given here in eV:

$$\begin{aligned} E &= hf - \phi \\ E &= 2.48 - \phi \end{aligned}$$

Note that for the electrons to jump, $E > 0$ so $\phi < 2.48eV$. Thus, it is important to choose a cathode with a low work-function. These materials appear to be rare compared to cathodes with higher work functions - some possible cathodes are Cesium ($\phi = 2.1eV$) or Sodium ($\phi = 2.28eV$) [2].

REFERENCES

[1] Prof. Mike Gal, "Physical waves", Lectures, *UNSW: PHYS1241*

[2] R Nave, ”Work Functions for Photoelectric Effect” *Hyperphysics* (2017), found at <http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/photoelec.html>, accessed 26 Oct. 2017

APPENDIX 1 - ADDITIONAL SPECTRAL LINES OF HELIUM AND HYDROGEN

These have been automatically generated. Here is the python source code, which generates data in a LaTeX table format:

```
import math

h = 4.1357 * 10**(-15) #eV s
c = 3 * 10**8 #m/s

Z = int(input('Atomic number: '))

E_0 = 13.6 #eV

def round_sigfigs(a, s):
    most_significant = int(math.floor(math.log10(abs(a))))
    answer = round(a, -most_significant + s - 1)
    if -most_significant + s - 1 < 1:
        answer = int(answer)
    return answer

for i in range(1, 8):
    for j in range(i+1, i+6):
        E_i = -E_0 * Z**2 / (i**2)
        E_j = -E_0 * Z**2 / (j**2)
        E = E_j - E_i
        wavelength_nm = (c*h/E) * 10**9
        print(' {0} & {1} & {2} & {3}\\\\'.format(
            j, i, round_sigfigs(E, 3), round_sigfigs(wavelength_nm, 3)))
```

All values are rounded to 3 significant figures, but because of how python prints decimals, trailing 0’s have been omitted.

Table 3: Helium

From	To	Energy (eV)	Wavelength (nm)
2	1	40.8	30.4
3	1	48.4	25.7
4	1	51.0	24.3
5	1	52.2	23.8
6	1	52.9	23.5
3	2	7.56	164
4	2	10.2	122
5	2	11.4	109
6	2	12.1	103
7	2	12.5	99.3
4	3	2.64	469
5	3	3.87	321
6	3	4.53	274
7	3	4.93	251
8	3	5.19	239
5	4	1.22	1010
6	4	1.89	657
7	4	2.29	542
8	4	2.55	487
9	4	2.73	455
6	5	0.665	1870
7	5	1.07	1160
8	5	1.33	936
9	5	1.5	825
10	5	1.63	760
7	6	0.401	3090
8	6	0.661	1880
9	6	0.84	1480
10	6	0.967	1280
11	6	1.06	1170
8	7	0.26	4770
9	7	0.439	2830
10	7	0.566	2190
11	7	0.661	1880
12	7	0.732	1690

Table 4: Hydrogen

From	To	Energy (eV)	Wavelength (nm)
2	1	10.2	122
3	1	12.1	103
4	1	12.8	97.3
5	1	13.1	95.0
6	1	13.2	93.8
3	2	1.89	657
4	2	2.55	487
5	2	2.86	434
6	2	3.02	411
7	2	3.12	397
4	3	0.661	1880
5	3	0.967	1280
6	3	1.13	1090
7	3	1.23	1010
8	3	1.3	955
5	4	0.306	4050
6	4	0.472	2630
7	4	0.572	2170
8	4	0.637	1950
9	4	0.682	1820
6	5	0.166	7460
7	5	0.266	4660
8	5	0.332	3740
9	5	0.376	3300
10	5	0.408	3040
7	6	0.1	12400
8	6	0.165	7510
9	6	0.21	5910
10	6	0.242	5130
11	6	0.265	4680
8	7	0.0651	19100
9	7	0.11	11300
10	7	0.142	8770
11	7	0.165	7510
12	7	0.183	6780