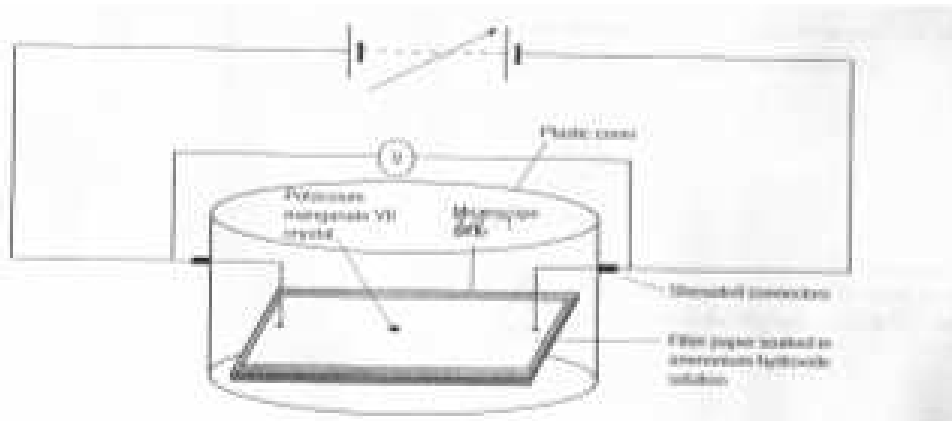


An Experiment to Investigate How Fast Electrons Move

Method

We set up the apparatus as shown below but instead of a microscope slide we used a petri dish. When the switch was closed a coloured band of manganate (VII) ions moved towards the positive terminal.



In order to measure the drift velocity of these ions we drew two lines on the filter paper and dropped the potassium manganate crystals between the negative terminal and first line. As the crystals drifted across the first line, we started stopwatches, one for each crystal. We stopped the stopwatches as they drifted across the second line. We then divided displacement by time to find the velocity of each crystal.

Measurements

Before commencing the experiment, we considered what precautions we could take to ensure accuracy. We drew start and finish lines on each piece of filter paper used, measuring the distance between the lines with a vernier calliper to achieve the most accurate reading that we could with the equipment available. We adjusted the voltage from the power supply whilst reading from a voltmeter (set to 600v) so that we could ensure the best accuracy possible from our voltage readings. We used stopwatches which measured to hundredths of a second as we were unsure as to how close the time differences would be between the crystals. We were unable to acquire scales that would measure a small enough amount of the crystals to use in

each experiment so we had to judge the size by eye. We were however advised that the size of the crystal would not affect the experiment and so we considered that this potential source of error may be negligible. We recorded all of our measurements which are shown below.

We felt that we could improve our accuracy further by performing a couple of trial experiments to see how we could improve upon our initial ideas. In our trial, we used a distance of 3.08cm and a voltage of 100v. We discovered that the crystal moved extremely slowly. We then increased the voltage to 250v and found that whilst the crystal appeared to move faster at this voltage, it was still very slow. We tried using different quantities of ammonia solution to see if this would affect the results. We found that the drift speed appeared faster with a larger quantity of solution but it was unclear as to whether some of this was due to diffusion. We tried varying quantities of ammonia solution in the Petri dish with the paper and concluded that the experiment would work best with a quantity of 2ml of ammonia solution and so this amount was fixed for our investigation to minimise the error due to the ammonia solution. We noted that there may be timing errors due to the thickness of the pencil lines and so used a sharp pencil with as fine a point as we could achieve. We were unable to remove the Petri dish and so had to clean and dry it as best as possible whilst it was in situ. We had to accept that this may lead to an error but we that we had minimised the error as best we could. We therefore decided to place three crystals in the dish at one time so that we would have comparable readings for each voltage and that the conditions for all three readings at a particular voltage would be as close to identical as we could achieve. We each timed one of the crystals which increased the error in timing due to differing reaction times but we felt this would be better than having one person attempt to time all three crystals to avoid confusion and further human error. We also noticed that the voltage changed during the

experiment and so we decided to note the varying voltages and take an average.

We checked that the terminals were in contact with the paper prior to commencing each experiment and recorded the following results.

Potential differences recorded (v)	Average Potential Difference (v)	Distance Moved (m)	Time Taken (s)	Average time taken (s)	Average Velocity (m/s)
101 – 103	102	0.0093	100.73		
			121.56		
			127.75	116.68	0.000080
No variation	149	0.0094	27.27		
			35.67		
			23.82	28.92	0.00033
No variation	201	0.0101	35.35		
			43.09		
			26.62	35.02	0.00029
248 – 250	249	0.0101	22.29		
			14.98		
			19.94	19.07	0.00053
291-300	296	0.0101	16.51		
			16.79		
			19.36	17.55	0.00058

We noted that, in general, that velocity increased with voltage. However, our readings taken at approximately 200v (201v in this case) did not support this theory. We decided to repeat the experiment for this voltage and obtained the following results

Potential differences recorded (v)	Average Potential Difference (v)	Distance Moved (m)	Time Taken (s)	Average time taken (s)	Average Velocity (m/s)
No variation	200	0.0099	22.06		
			45.07		
			37.13	34.75	0.00028

We noted that we had obtained similar results and we decided that our original findings should be included as a valid result for this experiment. Our original readings and not the second readings for approximately 200v have therefore been used to draw conclusions from this experiment.

Theory

Generally we consider the drift velocity of a flow of electrons as opposed to the speed of any one particular electron. However it is impossible to measure this. Instead, we investigated the drift velocity of manganate (VII) ions as a comparison. Initial observations suggest that the ions must be negatively charged, like electrons, to be attracted to the positive terminal and that they appear to move slowly although increase the voltage appears to increase the velocity.

If we were to calculate the drift velocity of a flow of electrons through a wire, we would use the equation $v = I/(nAe)$, where v is the drift velocity, n is the number of electrons in a unit volume of the wire, I is the current flowing and e is the charge of an electron.

We derive this from the knowledge that $Q = I \times t$. We know that in a certain amount of time, Q will pass through all points in the wire

We can calculate the distance that this electron moves in the same amount of time by using the equation distance = speed x time, so all electrons in a length of wire will pass through all points in the wire so

$$Q = (\text{volume of wire of length } (v t)) \times \text{number of electrons per unit volume} \times e$$

$$= A v t n e$$

$$I t = A v t n e$$

And dividing both sides by t gives

$$I = n A v e$$

However, since we are measuring the drift velocity of coloured ions through a medium, we cannot use this equation. We therefore decided to plot a graph of average velocity against voltage to see if there was a linear relationship i.e.

$$v = kV \text{ (Graph 1), where } k \text{ would be determined by the gradient of the straight}$$

line. We noted that whilst the velocity of the ions did appear to increase as the potential difference increased, with the exception of our readings at

approximately 200 volts, there was no linear relationship. We then

considered the possibility that there may be a relationship in the form $v = kV^a$.

We therefore plotted a graph (Graph 2) of $\log v$ against $\log V$ to determine if

there was a linear relationship where a would be determined by the gradient.

Potential Difference (v)	Log of Pd	Velocity (m/s)	Log of velocity
102	2.01	0.000080	-4.10
149	2.17	0.00033	-3.48
201	2.30	0.00029	-3.54
249	2.40	0.00053	-3.28
296	2.47	0.00058	-3.24

We did this because if $v = kV^a$, then $\log v = \log kV^a$ so $\text{Log } v = a \log kV$

Where $\text{Log } v$ is plotted on the y axis, $\log kV$ is plotted on the x axis (assuming k is one for the purposes of this experiment) and a would be the gradient. No linear relationship was found.

In conclusion, from graph 1, I have determined the gradients and therefore the relationship $v=kV$ at varying voltages.

Potential difference (v)	K (constant)
100	$0.00006/30 = 0.0000020$
150	$0.00011/25 = 0.0000044$
200	$0.00009/50 = 0.0000018$
250	$0.00008/65 = 0.0000012$
300	$0.00003/35 = 0.00000086$

We can only achieve a very approximate relationship of $v = V/1000000$ (m/s) by looking at the above table.

However, we need to consider the following errors.

Errors

Source of error	Average	½ smallest division	½ range	Use	%
Quantity of ammonia solution (ml)	2.1	+/- 0.0005	Not applicable	+/- 0.0005	0.02*
Distance travelled (m)	0.0098	+/- 0.00005	Not applicable	+/- 0.00005	0.51*
Voltage (v)	102	+/- 0.5	$\frac{(103 - 101)}{2} = 1$	+/- 1	0.98
Voltage (v)	149	+/- 0.5	Not Applicable	+/- 0.5	0.34
Voltage (v)	201	+/- 0.5	Not Applicable	+/- 0.5	0.25
Voltage (v)	249	+/- 0.5	$\frac{(250 - 248)}{2} = 1$	+/- 1	0.40
Voltage (v)	296	+/- 0.5	$\frac{(300 - 291)}{2} = 4.5$	+/- 4.5	1.52
Voltage (v) Average error					0.70*
Time (secs) 102 v	116.68	+/- 0.005	$\frac{(127.75 - 100.73)}{2} = 13.51$	+/- 13.51	11.58
Time (secs) 149 v	28.92	+/- 0.005	$\frac{(35.67 - 23.82)}{2} = 5.93$	+/- 5.93	20.50
Time (secs) 201 v	35.02	+/- 0.005	$\frac{(43.09 - 26.62)}{2} = 8.24$	+/- 8.24	23.53
Time (secs) 249 v	19.07	+/- 0.005	$\frac{(22.29 - 14.98)}{2} = 3.66$	+/- 3.66	19.19
Time (secs) 296 v	17.55	+/- 0.005	$\frac{(19.36 - 16.51)}{2} = 1.43$	+/- 1.43	8.15
Time (secs) average					16.59*
Total % error (Total *)					17.82

After considering the above table of errors, we amend our formula for drift velocity of ions as follows: -

$v = kV$ where $k = 1/1000000$ becomes

$$v = (1/1000000)V \pm 17.82 \% = (1/1000000)V \pm 0.0000001782$$

In order to improve the experiment I would measure the Potassium Manganate (VII) as it appeared that smaller quantities took longer than larger ones, although this could be partly due to diffusion. I would also consider trying to keep the paper in the dish in constant contact with the circuit however this would lead to its own problems in that I would then be unable to remove and replace the filter paper. I would also measure the current so as to calculate the resistance of the filter paper.

Ideas for further research

Despite being advised that the quantity of potassium manganate (VII) used would not affect the results of the experiment, our observations suggested that larger quantities had a greater drift speed. I would therefore suggest that an investigation into this, using the same set up as above but controlling the quantity of potassium manganate (VII) used, may be appropriate further research. This in turn may lead to a recommendation that this experiment should be carried out again using a controlled quantity of the substance or, alternatively, validate that the varying quantities used did not affect our results.

We also noticed that varying the quantity of ammonia solution affected results. Further research could be done into what the optimum amount of solution is for this experiment in order to improve results further and minimise errors caused by diffusion.