An Investigation to Measure the Viscosity of Golden Syrup.

Aim: - the aim of my investigation is to measure the viscosity of golden syrup and see if this value depends upon the temperature of the syrup.

Apparatus not included in diagram: - micrometer, 5 ball bearings as provided by the school, stop clock, magnet, marker pen, metre rule, weighing scales, thermometer, water bath. (The measuring cylinder is 50 cm^3)

Certain aspects have to be taken into account to ensure that the experiment is carried out safely. These are: -

- **If heating the syrup, be careful not to burn yourself on hot equipment.**
- **Goggles should be worn to prevent syrup from entering the eye.**

Variables that need to be considered are:- the size of the ball bearing to be dropped, the temperature of the syrup, the amount of syrup used, the length that the distance travelled is measured over, the depth beneath the top that the speed and distance are measured from, the type of syrup used and the density of the syrup.

I have decided to change the size of the ball bearing to see how this effects viscosity and a further study will be done changing the temperature of the syrup. The differing size ball bearings will be dropped at a constant temperature. To make this a fair test I will have to keep all other variables the same. To do this I will:-

- **Keep the amount of syrup used, the type of syrup (golden) used and the measuring cylinder that it is in the same.**
- **Mark the measuring cylinder so that I can measure time and distance from the same set values to the same end point.**
- **Leave a set distance at the top of the syrup to allow the ball bearing to accelerate to a constant speed.**

To measure the viscosity of golden syrup I will need to measure the radius of the ball bearing as this can be used in the formula $4/3\ \Pi r^3$ multiplying it by gravity and then the density of steel to calculate the weight of the ball bearing and calculate the downward force on the object. This came about as $m=\rho V$ and $W=mg$. Substituting in $W= \rho Vg$. The volume of a sphere = $4/3\Pi r^3$. Substituting in again, $W=4/3\Pi r^3\rho_{steel}g$.

r= radius of sphere (m)

ρ_{steel}=density of steel (7.8 g/cm3)

g=gravity (9.81m/s^2)

However, there is more than this acting on the ball bearing. Viscous drag is a force opposing the weight of the object and this is calculated by using Stokes' law. $F=6\Pi r\eta V$.

F=viscous drag (N)

r=radius of sphere (m)

η=coefficient of viscosity (Ns/m^2)

V=velocity (m/s)

Also, in an upwards direction is upthrust. This is calculated by the amount of the material displaced. As this is spherical (the ball bearing) this can be calculated by the formula $W=mg$. As $m=\rho V$ and $V=4/3\Pi r^3$ upthrust can be written as $4/3\Pi r^3\rho_{syrup}g$.

Putting all of these formulas in the same equation, depending on which direction they are acting you get to the equation: -

$4/3\Pi r^3\rho_{steel}g = 6\Pi r\eta V + 4/3\Pi r^3\rho_{syrup}g$

This is quite a lengthy equation and can be cancelled down to: -

$4/3r^2\rho_{steel}g = 6\eta V + {}^4/3r^2\rho_{syrup}g$

This can be used to plot a graph.

To analyse my results I will plot a scatter graphs for each temperature plotting velocity against the radius squared.

This can be shown by the equation calculated earlier: -

$4/3r^2\rho_{steel}g = 6\eta V + {}^4/3r^2\rho_{syrup}g$

Rearranging you get $6\eta V= 4/3r^2\rho_{steel}g - {}^4/3r^2\rho_{syrup}g$

Then put in the form $y=mx + c$

$$V = {}^{4g}/_{18\eta}\,(\rho_{steel} - \rho_{syrup})\, r^2$$

$$Y = \quad m \quad x \quad +c$$

y=V

$m = {}^{4g}/_{18\eta} (\rho_{steel} - \rho_{syrup})$
$x = r^2$

The gradient of the line of best fit can then be used to calculate the viscosity of syrup.

So, I will have to take measurements of the radius of the ball bearings, the density of syrup using $\rho = m/V$ and the velocity of the ball bearing. The density of the syrup can be found by putting a set volume of syrup ($50cm^3$) in a pre-massed measuring cylinder and then re-massing the cylinder with syrup after. The change in mass will give the mass of the syrup. The density will vary at different temperatures so will have to be measured at each temperature. These can be used to calculate the density. The density of steel is 7850 kgm^{-3}. The velocity can be found by speed = distance/time. So I will need to measure the time it takes the ball bearing to travel 10 cm down the measuring cylinder.

I will use five ball bearings ranging from 900 $\times10^{-5}$ in diameter to 150 $\times10^{-5}$ in diameter and at 20°C and then at 30°C and 40°C. I will repeat the experiment 3 times which means my results will be more reliable.

<u>Method</u>

1. Arrange apparatus as shown in diagram
2. Measure the distance between the two pen lines.
3. Measure the density of the syrup using the.
4. Drop the largest 9.00 $\times10^{-5}$ ball bearing into the syrup.
5. When it passes the upper line start the stop clock.
6. When it passes the lower line stop the stop clock.
7. Write down the time taken for the ball bearing to drop.
8. Extract the ball bearing from the syrup using a magnet.
9. Repeat steps 4-8 for the other four ball bearings.
10. Repeat steps 4-9 twice to ensure reliable results.
11. Repeat steps 1-10 for 30°C and 40°C.

Using the measuring cylinder to measure the volume of syrup can be measured to the nearest ±2ml. To do this accurately you must be at eye level with the top of the syrup and it must be within the scale of the measuring cylinder. The mass of the syrup is measured using weighing scales that measure to ±0.005 g. The radius of the ball

bearing can be measured to the nearest ±0.00001m using a micrometer. They will all be measured twice to ensure accuracy in the measurement and the micrometer must be placed across the diameter of the sphere. The distance travelled by the ball bearing, 0.100 metres will be measured by a metre rule between two lines on the measuring cylinder. A meter rule can be sensitive to the nearest ±0.0005m. This value will be measured twice if the same and thrice if not so to ensure accuracy in the reading. The ball bearing must be allowed time to accelerate to its terminal velocity in the syrup so the distance will start 0.030 metres below the top of the syrup. The time will be measured using a stop clock which is sensitive to the nearest 0.005 seconds. However, when using a stop clock human error comes into the equation when both starting and stopping the clock. This value will be close to ±0.5 seconds if both ends of the measuring cylinder are considered. To ensure that these readings are accurate you must be at eye level with the lines on the cylinder for the time, and the distance on the meter rule. The temperature of the syrup, especially at 40°C, will vary as when it is taken out of the water bath it immediately looses heat. The water bath is also at just above 40°C; somewhere around 45°C. This gives a sensitivity reading of the temperature of the syrup to ±5°C. All of the above must be measured accurately.

The viscosity of golden syrup should be calculated as the same value for all ball bearings used at the same temperature. This is due to the weight, upthrust and viscous drag all being affected by the radius of the ball bearing, so a change in the radius will affect all three equally, thus meaning no change in viscosity. Also, at the same temperature, the atoms in the syrup will be moving at the same speed and colliding with the ball bearing. As the size of the ball bearing decreases less collisions will occur meaning more viscous drag. However, this is proportional to the weight of the object and as the weight decreases, so will the number of collisions. These values are proportional to each other so the size of the ball bearing will differ the weight and the number of collisions. These two values are proportional to each other and acting in opposite directions so will cancel each other out.
As, the syrup heats up, the number of collisions will increase which will increase viscous drag, but this is outweighed by the weakening in bond strength as the temperature increases. The syrup will become

runnier and the ball bearing should pass smoother through the syrup as the density will have decreased.

Modifications

After reviewing the experiment there was numerous modifications that I had to make from my original plan. These are: -

- **The syrup had to be put back into the heated water in between dropping each separate ball bearing to ensure that the temperature was what it should be for each run.**
- **The distance allowed for the ball bearing to accelerate had to be shortened to accommodate for the shorter than anticipated length of the test tube from 0.03 meters to 0.025 meters.**
- **The distance timed to calculate the velocity of the ball bearing had to be shortened to accommodate for the shorter than anticipated length of the test tube from 0.10 meters to 0.07 meters.**
- **A 30 centimetre ruler was used to measure where to mark the distance timed on the cylinder rather than a meter ruler as it was easier to measure with the smaller ruler. This was due to the ruler being harder to hold due to its long length.**
- **The distance travelled had to be remarked after it had been in the water bath as the water washed the pen off.**

The table below shows the average size of the 5 ball bearings after measuring each with a micrometer twice to ensure accuracy.

Ball bearing	1	2	3	4	5
Diameter ($\times10^{-5}$ m)±0.00001m	900	634	316	199	150
Radius ($\times10^{-5}$ m) ±0.00001m	450	317	158	99.5	75
Radius Squared($\times10^{-7}$ m^2)±0.4 $\times10^{-7}$	203	100	25.0	9.9	5.6

<u>Density of syrup at varying temperatures</u>

Temperature (°C) ±5°C	Volume of syrup ($\times10^{-5}$l) ±0.02 l	Mass of measuring cylinder and syrup ($\times10^{-3}$kg) ±0.005 kg	Mass of measuring cylinder ($\times10^{-3}$kg) ±0.005 kg	Mass of syrup ($\times10^{-3}$kg) ±0.005 kg	Density (ρ) (kgm^{-3})
20	5.0	98.34	21.34	77.00	1540.0±6.4
30	5.0	98.08	19.58	78.50	1571.0±7.5
40	5.0	92.69	20.90	71.79	1435.8±6.0

Temperature (°C) ±5°C	20	30	40
Max Volume of syrup ($\times 10^{-5}$l)	5.02	5.02	5.02
Min Volume of syrup ($\times 10^{-5}$l)	4.98	4.98	4.98
Max Mass of measuring cylinder and syrup ($\times 10^{-3}$kg)	98.345	98.085	92.695
Min Mass of measuring cylinder and syrup ($\times 10^{-3}$kg)	98.335	98.075	92.685
Max mass of measuring cylinder ($\times 10^{-3}$kg)	21.345	19.585	20.905
Min mass of measuring cylinder($\times 10^{-3}$kg)	21.335	19.575	20.895
Max mass of syrup ($\times 10^{-3}$kg)	77.01	78.51	71.80
Min mass of syrup($\times 10^{-3}$kg)	76.99	78.49	71.78
Max Density (ρ) (kgm^{-3})	1546.4	1576.5	1441.8
Min Density (ρ) (kgm^{-3})	1533.7	1563.5	1429.9
Sensitivity (kgm^{-3})	± 6.4	±7.5	± 6.0

At room temperature

Ball bearing	Distance (m) ±0.0005m	Time 1 (s) ±0.5s	Time 2 (s) ±0.5s	Time 3 (s) ±0.5s	Average time (s)	Velocity ($\times 10^{-4}$m/s)
1	0.045	17.0	16.4	N/A	16.7±0.3	27.0±0.8
2	0.045	24.0	23.9	N/A	23.9±0.1	18.8±0.3
3	0.045	65.8	57.8	N/A	61.8±4.0	7.3±0.6
4	0.045	161.2	138.1	N/A	149.7±11.6	3.0±0.3
5	0.045	295.2	248.9	N/A	272.0±23.2	1.7±0.2

Ball Bearing	Max Distance (m)	Min Distance (m)	Max Average time (s)	Min Average time (s)	Max Velocity ($\times 10^{-4}$m/s)	Min Velocity ($\times 10^{-4}$m/s)	Sensitivity ($\times 10^{-4}$m/s)
1	0.0455	0.0445	17.0	16.4	27.7	26.2	±0.8
2	0.0455	0.0445	24.0	23.8	19.1	18.5	±0.3
3	0.0455	0.0445	65.8	57.8	7.9	6.8	±0.6
4	0.0455	0.0445	161.3	138.1	3.3	2.8	±0.3
5	0.0455	0.0445	295.2	248.8	1.8	1.5	±0.2

At 30°C

Ball bearing	Distance (m) ±0.0005m	Time 1 (s) ±0.5s	Time 2 (s) ±0.5s	Time 3 (s) ±0.5s	Average time (s)	Velocity ($\times 10^{-4}$m/s)
1	0.080	27.1	22.7	25.1	25.0±2.3	32±3.5
2	0.080	37.0	27.7	40.2	34.9±7.2	22.9±6.7
3	0.080	107.2	66.9	83.3	85.8±21.4	9.3±3.2
4	0.080	196.8	129.4	167.6	164.6±35.2	4.9±1.3
5	0.080	256.2	184.1	254.0	231.4±47.3	3.5±0.9

Ball Bearing	Max Distance (m)	Min Distance (m)	Max Average time (s)	Min Average time (s)	Max Velocity ($\times 10^{-4}$m/s)	Min Velocity ($\times 10^{-4}$m/s)	Sensitivity ($\times 10^{-4}$m/s)
1	0.0805	0.0795	27.3	22.7	35.5	29.1	±3.5
2	0.0805	0.0795	42.1	27.2	29.6	18.9	±6.7
3	0.0805	0.0795	107.2	64.4	12.5	7.4	±3.2
4	0.0805	0.0795	199.8	129.4	6.2	4.0	±1.3
5	0.0805	0.0795	278.7	184.1	4.4	2.9	±0.9

At 40°C

Ball bearing	Distance (m) ±0.0005m	Time 1 (s) ±0.5s	Time 2 (s) ±0.5s	Time 3 (s) ±0.5s	Average time (s)	Velocity (x10^{-4}m/s)
1	0.070	7.6	4.9	6.8	6.4±1.5	109.4±34.4
2	0.070	8.8	7.2	5.3	7.1±1.8	99.0±34.0
3	0.070	21.8	17.9	11.3	19.5±1.6	35.8±4.4
4	0.070	54.5	47.7	43.2	48.5±5.9	14.4±2.1
5	0.070	76.0	70.1	68.6	71.6±4.4	9.8±0.7
Anomalous Result Highlighted Repeated				18.9		

Ball Bearing	Max Distance (m)	Min Distance (m)	Max Average time (s)	Min Average time (s)	Max Velocity (x10^{-4}m/s)	Min Velocity (x10^{-4}m/s)	Sensitivity (x10^{-4}m/s)
1	0.0705	0.0695	7.9	4.9	143.8	88.0	±34.4
2	0.0705	0.0695	8.9	5.3	133.0	78.1	±34.0
3	0.0705	0.0695	22.1	17.9	39.4	31.4	±4.4
4	0.0705	0.0695	54.4	42.6	16.5	12.8	±2.1
5	0.0705	0.0695	76.0	67.2	10.5	9.1	±0.7

The error on the radius squared is calculated by squaring the radius with the error of ±0.00001 considered. Adding 0.00001 to 0.0045 = 0.00451. Squaring 0.00451 you get 203.4 $\times 10^{-7}$. This gives an error reading of ±0.4 $\times 10^{-7}$.

Temperature (°C)	Average Gradient	Maximum Gradient	Minimum Gradient
20	125.4	278.5	49.1
30	130	265.2	49.8
40	604.2	1700	183.3

The gradient of the line = 4g/18ŋ (p_{st} – p_{sy})

For 20 °C average gradient and average density
125.4 = 39.24/18ŋ (7850-1540)
125.4ŋ= 2.18 * 6310
125.4ŋ= 13755.8
ŋ=109.7 Ns/m^2
Maximum gradient and maximum density
278.5 = 39.24/18ŋ (7850-1546.4)
278.5ŋ= 2.18 * 6303.6
278.5ŋ= 13741.8
ŋ=49.3 Ns/m^2
Minimum Gradient and minimum density
49.1 = 39.24/18 ŋ (7850-1533.6)
49.1ŋ= 2.18 * 6316.4
49.1ŋ= 13769.8
ŋ=280.4 Ns/m^2

For 30 °C Average Gradient and average density
130 = 39.24/18ŋ (7850-1571)
130 ŋ = 2.18 * 6279
130 ŋ = 13688.22
ŋ = 92.5 Ns/m^2
Maximum gradient and maximum density
265.2 = 39.24/18ŋ (7850-1578.5)
265.2ŋ= 2.18 * 6271.5
265.2ŋ= 13671.9
ŋ=51.6 Ns/m^2

Minimum Gradient and minimum density
49.8 = 39.24/18 ŋ (7850-1563.5)
49.8ŋ= 2.18 * 6310
49.8ŋ= 13704.6
ŋ=275.2 Ns/m^2

For 40 °C Average Gradient and average density
604.2 = 39.24/18ŋ (7850-1435.8)
604.2ŋ = 2.18 *6414.2
604.2ŋ = 13983.0
ŋ = 23.1 Ns/m^2

Maximum gradient and maximum density
1700 = 39.24/18 ŋ (7850-1441.8)
1700ŋ= 2.18 * 6408.2
1700ŋ= 13969.9
ŋ=8.2 Ns/m^2

Minimum Gradient and minimum density
183.3 = 39.24/18ŋ (7850-1429.8)
183.3ŋ= 2.18 * 6420.2
183.3ŋ= 13996.0
ŋ=76.4 Ns/m^2

The error reading on the final viscosities can be calculated by finding the maximum displacement from the average viscosity at each temperature.

At 20°C, average viscosity =109.7 Ns/m^2 and the maximum displacement from the average viscosity =280.4 Ns/m^2 this gives an error reading at 20°C of 280.4-109.7 = ± 170.7 Ns/m^2

At 30°C, average viscosity =92.5 Ns/m^2 and the maximum displacement from the average viscosity = 275.2 Ns/m^2 this gives an error reading at 30°C of 275.2-92.5 = ± 182.7 Ns/m^2

At 40°C, average viscosity = 23.1 Ns/m^2 and the maximum displacement from the average viscosity =76.4 Ns/m^2 this gives an error reading at 40°C of 76.4-23.1 = ±53.3 Ns/m^2

So, the viscosity of the syrup at differing temperatures
At 20 degrees ŋ=109.7±170.7 Ns/m^2
At 30 degrees ŋ = 92.5±182.7 Ns/m^2
At 40 degrees ŋ = 21.5 ±53.3 Ns/m^2

The three graphs I have drawn showing the velocity of a ball bearing against its radius all show an increase in velocity as the radius squared increases in size. This relationship produces a curved line of best fit, suggesting that the velocity slows down considerably as the radius increases. Also, looking at the graphs and considering the temperatures that they are at, the velocity is slower, the lower the temperature. This is due to some of the intermolecular forces within the syrup being broken as the temperature increases due to the increase in energy input. Also, the attraction between syrup molecules depends on how far apart they are from each other. When they are close together the attraction is strong, but when they are further apart the attraction is weak. When the syrup molecules are cold, they are closer together and there is a strong attraction between them; this makes them more viscous. When the syrup is warmed up, the molecules start to move around and as a result of this they spend more time apart from each other thus meaning there is less attraction between the and making the syrup less viscous.

This causes the syrup to be runnier at higher temperatures thus meaning that the velocity of the ball should be faster through it at 40 °. This is in fact the case. This breaking of intermolecular forces lowers the viscous drag put on the object.
The graph comparing the viscosities of the syrup at different temperatures shows that the viscosity decreases considerably the higher the temperature. This is due to the lower density of the material at higher temperatures and the ball bearing can pass easier through the syrup due to this.
The viscosity of the syrup could have been affected at the same temperature by air bubbles within the syrup. These are totally random and could be found at any point in the syrup. As the ball bearings were dropped they were not always dropped in the same place (the centre) of the syrup. Due to this the ball bearings will have hit varying numbers of air bubbles and this could do one off two things to the viscosity:-

1. **Increase the viscosity of the syrup. This is due to the air bubbles being a circular shape, the strongest**

shape, and the ball bearing is not able to pass through the bubble. This means that the ball bearing is not flowing directly through the syrup and slows the velocity of the ball down. This turbulent flow could occur at any time and is incredibly hard to see so can not be accounted for.

2. The air bubbles could speed the velocity of the ball bearing up, as air is less dense than syrup, thus giving the impression that the viscosity of the syrup is less.

If I were to complete the investigation again and there were numerous resources that I could use there are a number of modifications that I would make: -

- Complete the experiment in a heat controlled room, pre setting the temperature to the desired one of the syrup. This would mean that the experiment could be completed quicker as you would not have to keep putting the syrup back in the water bath between the readings. This would lower the error readings on the temperature as it would not fluctuate as much.
- The distance the ball bearing travelled would be measured by a light gate which would accurately record the time taken. This would lower the error reading on the time and possibly lead to a change in velocity of the ball bearing.
- The distance the ball bearing travelled would be measured by laser measurement to ensure a precise reading.

Finally, I set out to find the viscosity of syrup, and as far as I know I have calculated this, as there is no value known to man. I, also, wanted to see if this value varied with the temperature that the syrup was at. I found that it did and as the temperature increased the viscosity decreased.