2007

IMPACT OF TEMPERATURE ON VISCOSITY

"Viscosity is the virtue by which a fluid offers resistance to the motion of a solid through it."

This document reports on an experiment that examined the relationship between temperature and viscosity. The terminal velocity and up-thrust experienced by a sphere of fixed weight and radius was calculated by dropping it into a measuring cylinder filled with glycerol heated to different temperatures. Using Stokes Law viscosity corresponding to each temperature level was worked out. This generated a range of data points with viscosity corresponding to each temperature level. These data points were statistically analysed. The results corresponded to those indicated by theory i.e. temperature and viscosity are inversely related; as temperature increased viscosity decreased.

This report is in five sections. The first details the plan and the science on which the experiment is based. The second describes implementation while the third analyses the results. The fourth section evaluates the both the experiment and its results. The fifth concludes.

1 Plan

1.1 The Question

Is viscosity affected by temperature? When temperature increases does viscosity decrease or increase and if it does are the changes systematic or random? These are the questions I investigate in this experiment.

1.2 Key Concepts

Archimedes' principle

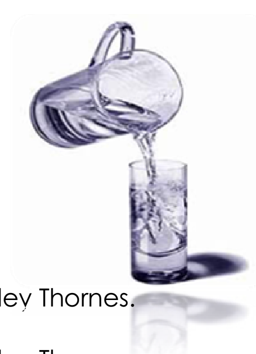
"A body immersed in a fluid (totally or partially) experiences an upthrust (i.e. an apparent loss of weight) which is equal to the weight of fluid displaced." [1]Ships don't sink in water because of upthrust. Upthrust is also the cause for weight loss when a body is partially or wholly immersed in a fluid.

Viscosity

"Viscosity is the virtue by which a fluid offers a resistance to the motion through it of any solid body."[2]

The theory of viscosity is almost identical to the theory of friction between two solids, just that viscosity is the term used for fluids. Viscosity is basically the resistance between the particles within a fluid.

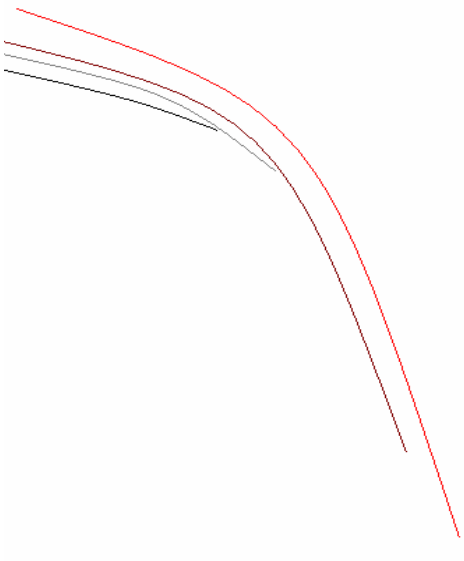
In a solid molecules are tightly packed i.e. there is a strong intermolecular force. Therefore when you move a solid, it moves as a whole as all the particles move together. In a fluid this is not the case. This is because due to lower intermolecular force the particles move at different velocities in relation to



[1] Muncaster, R. (1993). *A-Level Physics* (4th ed.). Gloucestershire: Stanley Thornes.

[2] Muncaster, R. (1993). *A-Level Physics* (4th ed.). Gloucestershire: Stanley Thornes.

each other. This feature can be understood by discussing what happens when pouring a jug of water into a glass. In liquids the molecules flow in layers. See the right - water flowing from a jug, it looks simple, but in reality it is quite complex.



Actually only the top layer of water is flowing, the bottom layer is still. This is explained with the help of the diagram on the left. The red line is the upper layer of water in the jug which flows in the glass, when this layer has flown into the glass the maroon layer starts flowing and the finally the black layer. This is because the black layer is closest to the solid (which in this case is the jug); the resistance offered by the solid is greater than the resistance offered by the layers of the liquid. This is because the number of molecules that make contact between the solid and the liquid layer are more than those that make contact between the liquid and liquid layer. The number of molecules that have contact between the liquid layer and air is the least.

Hydrogen Bonding

"Unusually strong dipole-dipole attractions that occur among molecules in which hydrogen is bonded to a highly electronegative atom."[3] Hydrogen bonding is a much stronger variant of Van Der Waals Forces. This strong bonding causes great friction between the layers of liquid and therefore gives glycerol its property of high viscosity. Glycerol has a high viscosity as opposed to other alcohols because, it has three –OH functional groups attached to it. Therefore more hydrogen bonds are formed, thus increasing the attraction between two neighbouring molecules (greater bond strength). Thus unlike alcohols that are volatile, glycerol is not only non-volatile, but is also very thick and viscous.

Stokes Law

Stokes Law plays an important part in understanding the motion of a solid (in his experiment he used a sphere) through liquids. "Stokes law states that when a body is under free fall in a tube containing a liquid of infinite length there is a point when there is no more acceleration in the body and the body reaches terminal velocity. Stoke further went on to say that this was due to the viscous forces acting within the liquid. The layers of the liquid in contact with the solid start moving with the velocity of the solid particle whereas the layers far away from the body remain at rest. The

[3] Products, P. S. (n.d.). *Glossary of terms*. Retrieved April 26, 2007, from O-Rings and Seals Problem Solving Products, Inc.: http://www.pspglobal.com/glossary-h.html

viscous forces being frictional forces act against the acceleration of the body and therefore there is a point when the viscous forces equal the resultant force driv ing the body. This is when the body reaches its terminal velocity. "[4]

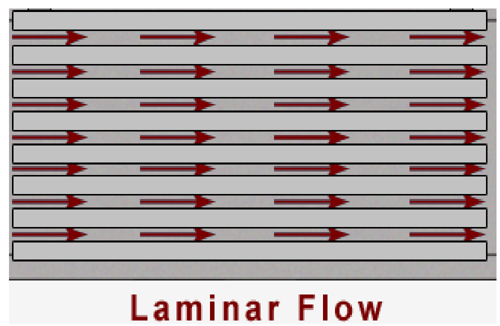
Through experimental verification Stoke proved that [5]

$$F = 6\pi r\eta v$$

Where:
F = viscous force
r= radius of ball
v= velocity of ball
η= viscosity coefficient

Laminar Flow

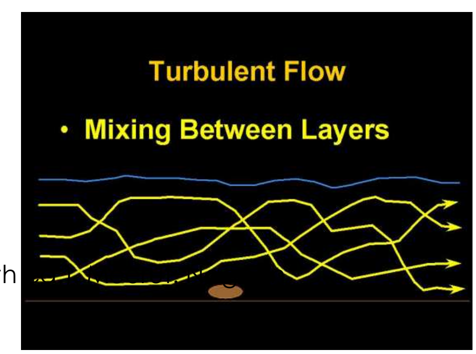
"The mechanics of a viscous fluid in which particles of the fluid move in parallel layers, each of which has a constant velocity but is in motion relative to its neighbouring layers."[6]



It is important that an appropriate liquid is chosen for the experiment. Liquids typically have two types of flow properties – Laminar and Turbulent. When flow is laminar it is possible to determine the point at which an object moving through it attains terminal velocity. This is because unlike liquids with turbulent flow, liquids with laminar flow exhibit constant viscous force. Laminar flow is dominated by viscosity and the viscous force experienced within the object remain s constant. Uniform viscosity throughout the liquid results in layers of flow, at different velocities in relation to on e another. Therefore for this kind of experiment it is important that we use liquids with laminar flow (e.g. glycerol).

Turbulent Flow

"Flow in which the velocity at any point varies erratically"[7]



[4] Authors interpretation from: Mittal, K. (2006). [illegible] (5th Prakashan.

[5] Wikipedia. (n.d.). *Stokes Law*. Retrieved February 16, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Stokes'_law

[6] Cornell. (n.d.). Laminar Flow . Retrieved March 26, 2007, from Cornell: http://www.utilities.cornell.edu/EIS/Glossary.htm

[7] Princetonl. (n.d.). Turbulent Flow . Retrieved March 26, 2007, from Princeton: http:// wordnet.princeton.edu/perl/webwn

In a liquid which has turbulent flow a particle of the liquid has variable velocity and do not flow in uniform layers. This results in varying velocity at different points within the liquid due to variations in viscous forces acting on the body. This prevents accurate determination of the point at which a body reaches terminal velocity. The importance of knowing the point at which a sphere reaches terminal velocity is because at this point the forces acting on the sphere are balanced. Using this feature it is possible to calculate the viscosity of an object at a particular temperature using Stokes Law.

Figure 3

1.3 Equipment

The following equipments will be needed to conduct the experiment.

- Measuring Cylinder – will be filled with glycerol. The ball will be dropped into the measuring cylinder after filling it with glycerol. The measures on the cylinder will help me calculate the velocity of the ball between two marked points on it.
- Thermometer – is used to determine the temperature of glycerol at any given time. Temperature readings will be on the x-axis of my viscosity – temperature graph.
- Glycerol – is the liquid used. I will calculate the density of glycerol at different temperature levels. This will be on the y- axis of my viscosity – temperature graph.
- Ball (Metal spheres from a ball bearing) – will be thrown into the measuring jar filled with glycerol to help me determine the viscosity of glycerol.
- Timer – used to determine time taken by the ball to travel between two marked points on the measuring cylinder. This will help me find the velocity of the ball.
- Crucible Tongs – is used to drop the ball bearing into the cylinder. Helps you ensure that no extra momentum is given to the ball at each drop/plunge.
- Specific Gravity Bottle – is used to measure the density of glycerol.
- Weighing Scales – is used to measure the mass of the ball and help in determining the density of glycerol.

Figure 3. Physical Geology Lecture Outlines # 3. (n.d.). Retrieved March 22, 2007, from http://www.geo.wvu.edu/~jtoro/geol101/streams/turbulent%20flow.jpg

- Meter Rule – is used to measure the distance between the two marked points on the measuring cylinder. This is used to calculate the velocity of the ball.
- Water Bath – is used to raise the temperature of the glycerol. This is required because I need to measure the viscosity of glycerol at different temperature levels.
- Freezer – is used to lower the temperature of glycerol. This is needed to determine the viscosity of glycerol at temperatures below room temperature.
- Micrometer – is used to measure the diameter of the ball.

1.4 Strategy

Background

This experiment is possible because the point at which an object reaches terminal velocity (i.e. when acceleration is zero. This is not to be mistaken with sationarity i.e. zero movement) while travelling through a liquid can be measured. This is the point at which upthrust, weight and viscous force balance each other.
When a spherical ball is dropped into a cylinder containing glycerol, you will notice that the ball initially accelerates and then reach a point where it attains terminal velocity. This is the point at which the ball is in equilibrium and all forces are balanced. Since the body is falling vertically there are no horizontal forces, and since the body is in equilibrium the vertical forces are balanced. The body reaches terminal velocity because when it is dropped into glycerol, there is friction created between the glycerol and the ball. This force of friction is called viscosity. There is also an upward upthrust force applied on the sphere. The Viscosity and the upthrust balance the downward weight of the body.

Fig. 1 illustrates how forces balance
(viscous force + upthrust = weight of sphere)
This happens when the body has reached
terminal velocity, i.e. acceleration is zero.

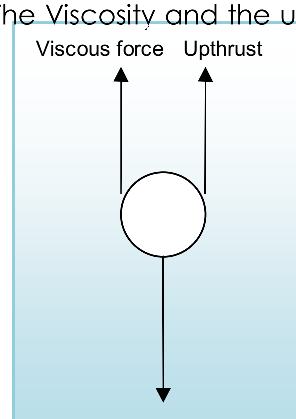


Fig. 1

During the course of this investigation I study the effect of temperature on upward viscous force. Since I am using the same ball for all calculations, the weight of the sphere remains unchanged. However the upthrust will have to be calculated at various temperatures because when you increase the temperature of glycerol its density decreases due to a lowering of intermolecular force of attraction.

Downward Force

From the picture it is clear that the only downward force is the weight of the sphere. The weight of the sphere can be calculated by multiplying mass by the force of gravity pulling it down. In order to find the mass of the sphere you need to use the formulae: $\frac{4}{3}\pi r^3\rho$(where r=radius of sphere and ρ=density of sphere)

Therefore weight = $\frac{4}{3}\pi r^3\rho g$ (r=radius of sphere; ρ=density of sphere; g=gravitational force)

Upward Force

There are two upward forces acting on the sphere namely the viscous force and the upthrust or the Archimedes Principle sometimes called buoyancy.

Buoyancy: "The upthrust is equal to the weight of the displaced liquid." "[8]

Viscous force: "Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction." [9]

Upthrust and viscosity balances the weight of the sphere and when this happens the object is said to have reached terminal velocity. At this point we can say that:

viscous force + upthrust = weight of sphere

Viscous force = $F = 6\pi r\eta v$ (Stokes Law)

upthrust = mass of liquid displaced (Archimedes Principle)

Weight of sphere= mg (mass x gravity)

Therefore we come up with the equation:

$$6\pi r\eta v + \left(\frac{4}{3}\pi r^3\rho_f g\right) = \frac{4}{3}\pi r^3\rho_s g$$

$$6\pi r\eta v = \frac{4}{3}\pi r^3(\rho_s - \rho_f)g$$

$$\eta = \frac{2r^2(\rho_s - \rho_f)g}{9v}$$

Where

ρ_s is the density of the sphere.

ρ_f is the density of the fluid (glycerol in this case).

[8] Wikipedia. (n.d.). *Stokes Law*. Retrieved February 16, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Stokes'_law

[9] *Viscosity*. (n.d.). Retrieved April 28, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Viscosity

Safety

"Glycerol is generally regarded as a safe material for which no special handling precautions are required. However, it is flammable. It also feels oily, so may be a slipping hazard if spilled on the floor." [10]

Eye contact: Immediately flush the eye with water. If irritation persists, call for medical help.
Skin contact: Wash off with water.
If swallowed: Call for medical help if the amount swallowed is large. Glycerol is widely used in foods, so accidental consumption of a s mall amount is unlikely to be harmful.

Care needs to be taken while handling the water bath. Hot water may burn your skin. If you come in direct contact with the hot water, immediately pour running cold water over the affected area.

Most of the other equipment and material is harmless, if used sensibly, and carefully.

Precision and Reliability

Thermometer – is not very precise since you can measure only integers; you cannot go to even a single decimal place. On the other hand the thermometer is an extremely reliable piece of equipment. A thermometer in working order will give you near accurate reading, and is easy to read. A digital thermometer may have been better, but for this kind of experiment the additional cost is not justified.

Timer –a digital timer is precise up to two decimal places therefore it is more appropriate to use as opposed to an analog timer . This degree of precision is sufficient for an AS level practical as it gives you near enough results to the true value. Its digitally mastered te chnology can be considered to be reliable.

Specific gravity bottle – finely shaped with precision, the specific density bottled is a very accurate and precise piece of equipment. A major part of the precision will depend on the weighing scales and how it is used. It is important to ensure that the density bottle is clean and that there is no glycerol stuck on its outer surface as this affects the density reading.

Weighing scales – I have used a digital weighing scale with accuracy of up to two decimal places. I used this as opposed to a kitchen scale because they are less precise and are more prone to measurement error. The weighing scale is precise,

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[10] Education, C. -E. (n.d.). *Chemical Safety Data: Glycerol.* Retrieved 2007 26, April, from Physical and Theoretical Chemistry - University of Oxford: http://ptcl.chem.ox.ac.uk/~hmc/hsci/chemicals/glycerol.html

but there may be a reliability issue. The values at times keep changing when the weight is in between two values, e.g. true weight may be 86.775 gm when on the weighing scale you get a reading of 86.77g and 87.78g flickering between each other, so you don't know what value to use. Another problem is that the weighing scale does not always start at zero. The tare button should therefore be pressed before each weighing.

Meter Rule – is not the most accurate of devices, but is sufficient for our calculations. Its precision is up till one mm. This is a decent value for viscosity. Its reliability is wholly dependent on the power of perception of the human eye and mind.

Micrometer – is a very sensitive device. It helps measure the radius of the ball to an accuracy of 0.01mm. It is preferred over the vernier calliper due to its superior precision and presence of a ratchet that ensures measurement of diameter without affecting form.

Constants

During the course of this investigation a number of factors will need to be kept constant.

Diameter and the weight of the ball - Having the same diameter and weight of the ball or using the same ball time and again yields results that are comparable.

Liquid used (glycerol) - Each liquid has its own coefficient of viscosity and therefore you cannot compare the temperature to the viscosity if you are using two different liquids.

The height from which you drop the ball - The height from which you drop the sphere is not extremely important but if you drop it from different heights for different trials you destroy the validity of the results. This is because when a body drops from a higher height it drops with a higher velocity before touching the surface of the liquid. Therefore you will need a greater viscous force in order to make the body attain its terminal velocity; this will result in a shift in the position at which the sphere reaches terminal velocity.

Variables

Temperature - Since the aim of the experiment is to find the relationship between temperature and viscosity I will alter glycerol's temperature to be able to map its impact on viscosity.

Density of glycerol - When you alter temperature you will automatically alter the density of the liquid, this is because the intermolecular forces of attraction will increase when the temperature decreases.

Velocity of sphere - The velocity of the sphere will continuously alter because the viscosity keeps changing therefore the ease with which the ball flows through the liquid will change.

1.5 Hypothesis

While conducting the experiment I have made several assumptions. These are listed below.

1. Since glycerol is thick and does not flow easily its viscosity is high. I therefore expect the sphere to attain terminal velocity quite early in its journey through glycerol within the measuring cylinder.
2. The sphere will drop faster as the temperature increases, and vice versa.
3. As temperature increases density will decrease.
4. Since density decreases as temperature increases the velocity of the sphere in its early journey within the liquid will increase as temperature increases.
5. Since the sphere travels at higher velocity at higher temperature, viscosity decreases as temperature increases.[11]
6. The opposite of the above is also true i.e. as temperature falls density and viscosity increases and the sphere travels slower and for a shorter distance before it attains terminal velocity.

I hope to prove the above in the course of my investigation.

[11] Inferred from: Summers, H. (1992, July 27). *Dependence of viscosity on temperature*. Retrieved April 14, 2007, from Radio, Electronics and Computing Projects: http://www.hanssummers.com/electronics/viscometer/exptemp.htm

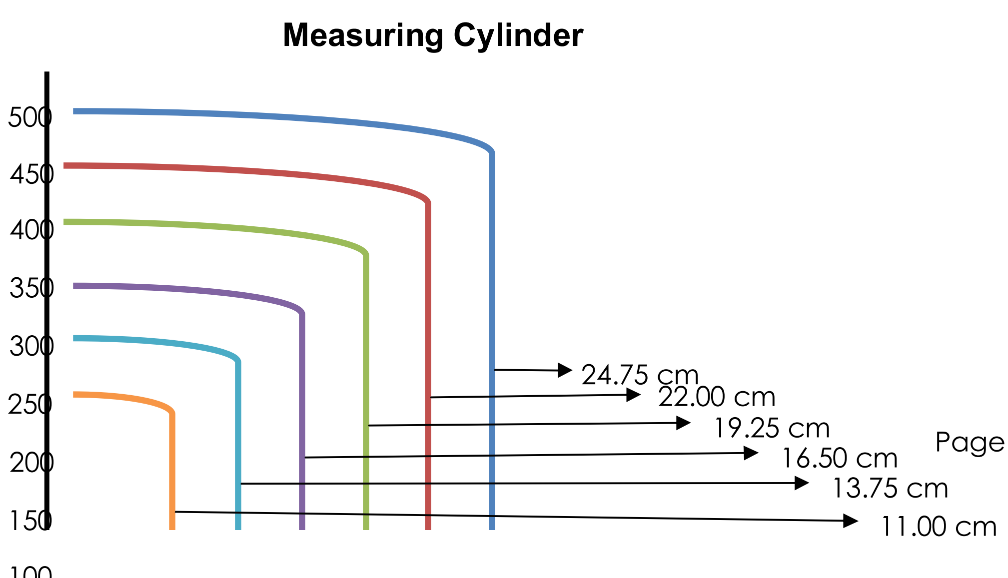
1.6 Testing

During the preliminary round of my experiment I test to see if my choice of measuring jar and glycerol as the fluid match the size and drop height of the sphere. This is important because if the ball does not attain terminal velocity before reaching the bottom of the jar the experiment becomes meaningless. This also helps me decide the appropriate height from which to drop the sphere. The preliminary round also helps me check for avoidable errors.

Aims of the preliminary experiment:

- To find out whether the sphere reaches terminal velocity within the glycerol, at room temperature.
- To observe the velocities of the sphere at different distances within the liquid.
- To identify factors that would affect my investigation and would cause errors.
- To try and minimize the above factors.
- To determine the feasibility of hypotheses made earlier.
- To use it as a base for conducting my actual experiment.

My results were obtained by dropping the ball from a height of 7.0 cm from the edge where the glycerol starts. This helps the ball generate initial velocity before entering the glycerol. As soon as the ball enters the glycerol reached terminal velocity quickly. This is why I will be using a height of 7.0 cm even for my actual experiment.



I threw the ball in the manner as shown above (measured the time taken for each distance interval shown on the picture). I took the time taken for the ball to fall through different distances. Since I now have the time and the distance I can determine the velocity of the ball.

This was done by using the formula: velocity = $\frac{\text{distance}}{\text{time}}$

I have recorded my results below. The velocities were calculated using average times.

Below is a tabulation of results from my intermediate tests to find out the point where the ball bearing reaches terminal velocity in the measuring cylinder at room temperature. This is important because I then have to judge if at higher temperatures the ball will be able to reach terminal velocity before reaching the bottom of the jar.

Distance	**Marking on cylinder**	**1st time trial**	**2nd time trial**	**3rd time trial**	**Average velocity**
24.75 cm	**500-50**	3.23 s	3.19 s	3.21 s	7.710 cms^{-1}
22.00 cm	**450-50**	2.89 s	2.89 s	2.91 s	7.612 cms^{-1}
19.25 cm	**400-50**	2.51 s	2.52 s	2.53 s	7.639 cms^{-1}
16.50 cm	**350-50**	2.16 s	2.14 s	2.15 s	7.674 cms^{-1}
13.75 cm	**300-50**	1.78 s	1.76 s	1.79 s	7.681 cms^{-1}
11.00 cm	**250-50**	1.42 s	1.45 s	1.44 s	7.639 cms^{-1}

From the above it is clear that the ball bearing has reached terminal velocity at the 450 marking on the measuring cylinder (a slight variation may be allowed due to various errors discussed on the errors page towards the end of the investigation).

Thus I have proved my first hypothesis.

The results attained above prove that my experiment is doable and that the viscosity of glycerol is high enough so that the ball reaches terminal velocity within the jar and there is enough space to determine the velocity of the ball at different temperatures.

I therefore hope to prove the remaining five hypotheses in the final experiment.

Factors affecting experiment

I have taken the following precautions so as to enhance the outcome of my final result.

- Prevent air bubbles from entering the liquid because it hampers the true value.
- Avoid parallax errors.
- Avoid contamination of glycerol.
- The ball is dropped from the same height at each trial.
- Use same ball for maximising accuracy.
- Mix glycerol so that temperature is even throughout the liquid.
- Measured time thrice for each trial in order to reduce error due to slow reflexes. The results were averaged to reduce the scope for errors.

2 The Experiment

The main experiment that follows seeks to substantiate results from my preliminary round and prove my hypothesis. This round will be done after eliminating all avoidable errors, and after true understanding of the subject matter. I am hoping to find that there is a direct relationship between viscosity and temperature, as hypothesised. In my final experiment I hope to get various values for viscosity at different temperatures, and by using the data at hand I will draw a graph. The success of the preliminary experiment will confirm the practicality of my final experiment. The final experiment is where I prove or disprove my hypothesis.

2.1 Mass

To find the mass of the ball bearing you need a weighing scale.
I pressed the tare button on the weighing scale to eliminate any zero error.
I then placed the ball bearing on the weighing scale and recorded the reading from the display.
I got a value of 0.88grams as the mass of my sphere.

2.2 Volume

In order to find the volume of the ball I measured its radius and used the formula:

$$\frac{4}{3}\pi r^3$$

where 'r' is the radius of the ball..

To find the radius of the ball bearing I need to find its diameter using a micrometer.

I ensured that the micrometer had no zero error.

I placed the sphere in between the jaws of the micrometer and measured the reading on the main scale and then on the circular scale.

During my experiment the diameter of the ball bearing was recorded as 6.01mm.

I used this to calculate the radius as $(\frac{diameter}{2})$ = 0.3005 cm.

Since I now know the radius of the ball I used this to calculate the volume of the ball using the following formula.

$$\frac{4}{3}\pi \times 0.3005^3$$

This yielded a value of 0.1137 cm^3.

2.3 Velocity

I took two marked points on the measuring cylinder.

I made sure that the marked points are a good distance apart and are below the point where the ball reaches terminal velocity so that the upward and downward forces are balanced.

During my experiment the points were 20 cm apart.

I took three separate readings for the time taken by the ball bearing to travel between the two marked points; these reduce any errors, and give a figure closer to the actual figure.

Since I had the time taken and I knew the distance i.e. 20cm I calculated the velocity using the formula

$$velocity = \frac{distance}{time}$$

To find average time from three trials I used the formula

$$\frac{sum\ of\ all\ 3\ time\ trials}{3}$$

I repeated this procedure for various temperatures.

The results obtained proved my second hypothesis.

Given below is the table of results from my experiment.

Temperature (□C)	Distance (cm)	1st time trial (s)	2nd time trail (s)	3rd time trial (s)	average time (s)	velocity cms^{-1}

-10	20	89.07	85.27	87.53	87.29	0.23
-9	20	52.89	49.03	54.72	52.21	0.38
-8	20	37.8	34.68	33.89	35.46	0.56
-5	20	31.85	27.5	29.66	29.67	0.67
0	20	19.6	18.7	15.21	17.84	1.12
9	20	5.67	5.78	5.02	5.49	3.64
10	20	4.95	4.92	4.83	4.9	4.08
15	20	4.49	4.56	4.27	4.44	4.50
20	20	2.47	2.34	2.55	2.45	8.16
25	20	1.99	1.86	1.93	1.93	10.36
30	20	0.85	0.86	0.73	0.81	24.69
35	20	0.69	0.65	0.61	0.65	30.77
40	20	0.52	0.58	0.47	0.52	38.46
45	20	0.47	0.44	0.41	0.44	45.45
50	20	0.38	0.35	0.33	0.35	57.14
55	20	0.25	0.28	0.3	0.28	71.43

REFER TO APPENDIX – C FOR VELOCITY AGAINST TEMPERATURE GRAPH

2.4 Density of glycerol

To find the density of glycerol I used the specific gravity bottle. A specific gravity bottle is a transparent bottle with a lid on top. The lid on top of the specific gravity bottle has a small hole running through its centre. The use of the hole is to remove any excess glycerol contained inside the bottle. A lid without a hole would force the liquid inside the bottle thereby altering the pressure since the liquid has nowhere to go; this alters the true reading of the density; whereas the specific gravity bottle always has the same volume of liquid inside it.

NOTE: All the readings for mass were taken by using the weighing scale.

First I weighed the empty bottle.
Weight of empty bottle = m_1
I then weighed the bottle with water inside
Weight of empty bottle + water = m_2
I then calculated weight of water in bottle as $m_2 - m_1$
Since I know that the density of water is 1 gm/cm^3
I calculated the volume of the bottle by using the formula

$$volume = \frac{mass}{density}$$

During my experiment m_1 = 24.67 g.

During my experiment $m_2 = 72.58$ g.
During my experiment $m_2 - m_1 = 47.91$g.

$$volume = \frac{47.91}{1}$$

Therefore volume of water = volume of container = 47.91 cm^3

Since I know the volume of the container, I need to find the mass of glycerol in the container for various temperatures and the use the above formulae to find the density of glycerol at various temperatures. The results obtained proved my hypothesis i.e. as temperature increases density decreases.

During my experiment I obtained the following results

Temperature (□C)	volume of container (cm^3)	mass of glycerol (g)	Density (gcm^{-3})
-10	47.91	60.8	1.2690
-9	47.91	60.75	1.2680
-8	47.91	60.70	1.2670
-5	47.91	60.61	1.2651
0	47.91	60.56	1.2640
9	47.91	60.46	1.2619
10	47.91	60.37	1.2601
15	47.91	60.32	1.2590
20	47.91	60.27	1.2580
25	47.91	60.08	1.2540
30	47.91	60.03	1.2530
35	47.91	59.94	1.2511
40	47.91	59.7	1.2461
45	47.91	59.6	1.2440
50	47.91	59.5	1.2419
55	47.91	59.22	1.2361

These results prove my hypothesis.

2.5 Density of Ball

To find the density of the ball we use the formulae:

$$density\ of\ ball = \frac{mass\ of\ ball}{volume\ of\ ball}$$

From the above calculation we have already determined the mass and the volume of the ball. Therefore density of ball =

$$density = \frac{0.88}{0.1337} = 7.746\ gcm^{-3}$$

2.6 Upthrust

Upthrust is a force resisting the motion of the ball as it travels through the flui d. It is the weight of the liquid displaced. To measure the weight of the liquid (glycerol) displaced we use the formula

$$weight\ of\ glycerol\ displaced = density\ of\ glycerol\ \times volume\ of\ glycerol\ displaced\ \times g$$

We have already calculated the density of glycerol at various temperatures. It is not possible to find the volume of glycerol displac ed with the equipment at hand. But the volume of the ball bearing will be the same as the volume of liquid displaced.

Therefore

$$weight\ of\ glycerol\ displaced = density\ of\ glycerol\ \times volume\ of\ ball\ \times g$$

During my experiment the following were the various values for upthrust

Temperature (□C)	Density (g cm^{-3})	volume of ball (cm^3)	Upthrust (g cm s^{-2})
-10	1.2690	0.11360	141.4322
-9	1.2680	0.11360	141.3159
-8	1.2670	0.11360	141.1996
-5	1.2651	0.11360	140.9902
0	1.2640	0.11360	140.8739
9	1.2619	0.11360	140.6413
10	1.2601	0.11360	140.4319
15	1.2590	0.11360	140.3156
20	1.2580	0.11360	140.1993
25	1.2540	0.11360	139.7573
30	1.2530	0.11360	139.6410
35	1.2511	0.11360	139.4317
40	1.2461	0.11360	138.8734
45	1.2440	0.11360	138.6408
50	1.2419	0.11360	138.4081
55	1.2361	0.11360	137.7568

2.7 Viscosity

In the planning section of this report I had said that

Weight of the ball bearing = viscous force + upthrust (when the ball is at terminal velocity)

So far I have found the weight of the ball bearing and upthrust . I now need to find the viscosity of glycerol at different temperatures.

Viscous force = $6\pi r\eta v$

Weight of ball bearing = mg

Upthrust = weight of glycerol displaced.

Therefore: $6\pi r\eta v + weight\ of\ glycerol\ displaced = mg$

As proved in my strategy section of the investigation to find η (viscosity) we use the formula:

$$\eta = \frac{2r^2(\rho_s - \rho_f)g}{9v} \quad \text{or} \quad \eta = \frac{mg - upthrust}{6\pi r v}$$

The following table has the results I obtained for viscosity

Temperature (□C)	Velocity (cm s^{-1})	Density of glycerol (g cm^{-3})	Radius of ball (cm)	Density of ball (gm cm^{-3})	Force due to gravity (cm s^{-2})	Viscosity (P) poise (gm cm^{-1} s^{-1})
-10	0.23	1.269	0.3005	7.74606	981	556.4906
-9	0.38	1.268	0.3005	7.74606	981	332.9002
-8	0.56	1.267	0.3005	7.74606	981	226.1341
-5	0.67	1.265	0.3005	7.74606	981	189.2688
0	1.12	1.264	0.3005	7.74606	981	113.8212
9	3.64	1.262	0.3005	7.74606	981	35.0376
10	4.08	1.26	0.3005	7.74606	981	31.2818
15	4.50	1.259	0.3005	7.74606	981	28.3495
20	8.16	1.258	0.3005	7.74606	981	15.6457
25	10.36	1.254	0.3005	7.74606	981	12.3326
30	24.69	1.253	0.3005	7.74606	981	5.1766
35	30.77	1.251	0.3005	7.74606	981	4.1553
40	38.46	1.246	0.3005	7.74606	981	3.3268
45	45.45	1.244	0.3005	7.74606	981	2.8159
50	57.14	1.242	0.3005	7.74606	981	2.2406
55	71.43	1.236	0.3005	7.74606	981	1.7941

These results have proved my hypothesis

REFER TO APPENDIX-A FOR THE VISCOSITY TEMPERATURE GRAPH

3 Analysis

Temperature (□C)	Density of glycerol (g/cm^3)	Upthrust (g cm s^{-2})	velocity (cm/s)	viscosity (P) poise

-10	**1.269**	**141.4322**	**0.2291**	**556.4906**
-9	**1.268**	**141.3159**	**0.3830**	**332.9002**
-8	**1.267**	**141.1996**	**0.5640**	**226.1341**
-5	**1.265**	**140.9902**	**0.6740**	**189.2688**
0	**1.264**	**140.8739**	**1.1210**	**113.8212**
9	**1.262**	**140.6413**	**3.6429**	**35.0376**
10	**1.26**	**140.4319**	**4.0816**	**31.2818**
15	**1.259**	**140.3156**	**4.5045**	**28.3495**
20	**1.258**	**140.1993**	**8.1632**	**15.6457**
25	**1.254**	**139.7573**	**10.3626**	**12.3326**
30	**1.253**	**139.6410**	**24.6913**	**5.1766**
35	**1.251**	**139.4317**	**30.7692**	**4.1553**
40	**1.246**	**138.8734**	**38.4615**	**3.3268**
45	**1.244**	**138.6408**	**45.4545**	**2.8159**
50	**1.242**	**138.4081**	**57.1428**	**2.2406**
55	**1.236**	**137.7568**	**71.4285**	**1.7941**

- Above are all the variables from my experiment.
- As you can see there is only a very slight variation in the density of glycerol over the range of temperatures. Therefore I could have omitted the various results for density and just used any one or preferably the average. However for the sake of accuracy I decided to make density a variable and consequently upthrust became a variable as well.
- As predicted in my hypothesis my main finding is that as temperature increases viscosity decreased. This can be seen in my results, which show a clear connection between viscosity reduction and temperature increase. Most of my results are in line with the best fit curve.
- From the results we can also see that as the temperature increases density decreases.
- As density decreases so does the viscosity. This is because as the molecules start moving further apart there is more space for the ball beari ng to flow freely therefore lees obstruction in the path of the ball bearing and therefore less viscosity.

$$\eta = \frac{2r^2(\rho_s - \rho_f)g}{9v}$$

From the above equation you can clearly see that η is proportional to the density, and inverse to the velocity.

- As the viscosity and density decrease the velocity increases. As there is less obstruction to the flow of the ball bearing the ball falls faster and therefore velocity increases.
- As the density decreases so does the upthrust this is because upthrust is the weight of liquid displaced and as the density of the liquid decreases do does the weight. Therefore as viscosity decreases so does the viscosity.

  $$\eta = \frac{mg - upthrust}{6\pi rv}$$

  From the above equation it is clear that viscosity and upthrust are proportional (since weight is constant).
- The graphs drawn at the end show a clearer picture as to the true nature of the relationship between viscosity and temperature.
- My results are satisfactory and may be deemed accurate if errors are accounted for. I have talked of various errors later on in the investigation.
- I have arrived at conclusive results which helped me make a clear connection between the variables present during the course of this investigation i.e. temperature, viscosity, density, upthrust, velocity.
- Thus on the whole my sets of results are satisfactory and analysis coincides with my hypothesis.

3.1 Tangents

I have drawn 3 tangents on the viscosity temperature graph. To find the slope of the line you use the formula:

$$slope = \frac{\Delta y}{\Delta x}$$

Where: Δy is the difference in the values on the y-axis

Δx is the difference in the values on the x-axis

Slope of the first tangent (t_1) = -30

Slope of the second tangent (t_2) =- 7.3

Slope of the third tangent (t_3) = -0.63

From the above results it is clear that for tangent t_1 which ranges from -10□C to -5□C there is a steeper slope as compared to t_2 which ranges from 0□C to 10□C. Both of the tangents have a steeper slope compared to t_3 which ranges from 15□C to 30.75□C. This trend signifies that as the temperatures get higher the rate of change of viscosity decreases. At lower temperatures when the glycerol is heated slightly the viscosity has a sudden drop, whereas at higher temperatures if you increase the temperature further the viscosity undergoes a slight gradual drop. From these results it can be inferred that temperature and viscosity do not have a direct proportional relationship. The rate of change of viscosity changes at various temperatures.

4 Evaluating Evidence and Procedures

- This investigation has yielded desired results i.e. a clear connection between temperature and viscosity.
- All the points on all three of the graphs drawn do not lie exactly on the line. This is because of limitations due to instruments and human limitations.
- For example the meter rule can measure only up to two decimal places.
- The micrometer can measure up to 3 decimal places . I used the micrometer over the vernier callipers because it is more accurate.
- In spite of all of the above the results fall within range.
- The various errors are mentioned in the next page.
- On my viscosity temperature graph there is one anomalous result which I have circled on the graph, this is presumably due to human error since I got all my other results on the line of curve. This error is mainly in recording the time taken for the ball bearing to traverse the marked distance. The anomalous result was for temperature 9□C and as from the table above it is evident that there is a slight gap in the timings. This may be due to the following result:
    - When you drop the ball bearing you must make sure that the ball is dropped at the same place in the measuring cylinder because if it is dropped on the sides the wall of the measuring cylinder may cause friction. In order to lower this error it is advisable to use a measuring cylinder with a larger cross sectional area, to give you more room to throw the ball.
    - There is also a possibility that since the experiment was conducted in a room which was at room temperature and therefore the heat of the room was higher than the heat of the glycerol this would have created convection heat currents and the heat from the glycerol got dissipated into the atmosphere. This heat dissipation is not uniform since the top layer of glycerol is in direct contact with the atmosphere it will lose heat more easily. Therefore it is essential to keep mixing the mixture in order to prevent uneven temperatures. It is also advisable that the temperature be measured from the middle of the marked distance on the measuring cylinder as this will give the mean temperature for the chosen distance.
    - Air bubbles get trapped in the glycerol especially at low temperatures . This is because at low temperatures glycerol has a high viscosity and therefore the movement of the bubbles is restricted due to high friction. Whereas at high temperatures the viscosity decreases and therefore it is easier for the air bubble to escape. So great care must be taken while pouring the glycerol into the measuring cylinder to

avoid air bubbles. These air bubbles interfere with the falling of the ball bearing, the act as an obstruction and alter the true reading for the velocity of the ball bearing.

- Most errors are avoidable and I have tried to prevent them from affecting my results. However the accuracy of the equipment cannot be altered and hence in order to compensate for the error we take a percentage error that I have worked out in the errors section. This gives shows a deviation from the original value as a result of the limitations of the equipment.

4.1 Errors

Random Errors

"Errors that occur due to natural variation in the process. Random error is typically assumed to be normally distributed with zero mean and a constant variance. Random error is also called experimental error." [12]

The errors associated while trying to read a meter rule is random error. You cannot tell the exact value because the precise value might be slightly above or below the marked value.

Random errors can be reduced by using better equipment, techniques and by averaging results, However they can never be completely eliminated.

Systematic Error

"A consistent error of the same size and sign produced in a measurement process due to the same recurring cause."[13]

This kind of errors are like those associated with a weighing scale, when it is not correctly calibrated to zero.

Systematic errors can be reduced or even completely removed; this improves the accuracy of the results.

Systematic error is mainly caused due to human negligence.

Common Errors Encountered

- "Parallax error is apparent shifting of objects when the viewing position is changed."[14]

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[12] Glossary. (n.d.). Retrieved April 23, 2007, from Accelerated Technology Laboratories: http://www.atlab.com/LIMS/glossaryp-t.html

[13] Glossary. (n.d.). Retrieved April 23, 2007, from Accelerated Technology Laboratories: http://www.atlab.com/LIMS/glossaryp-t.html

[14] The Instrumentation Center - Metrology Services . (n.d.). Glossary of Terms. Retrieved March 25, 2007, from ticms: www.ticms.com/wizard/glossary.htm

This error is easily made while doing an experiment of this nature since you have to start the stop watch at a particular point and then immediately stop it when it crosses the next point. While doing so it is not entirely possible to line your eye of vision right in front of the two points which results in parallax error which make you look at a point at an angle, which will make the point seem closer or further away from where it actually is. This error is usually of a cumulative nature, and can be rectified by choosing a large distance which gives the reader more time to align his eye in front of the second point. This kind of error is a systematic error, and was therefore corrected during the course of the experiment.

- While dropping the ball into the cylinder it has to be ensured that the ball falls through the centre of the glycerol because if it sticks to the wall of the cylinder or flows near it the wall will also provide friction against the ball falling. This is a systematic error that can be avoided by being careful and making sure the ball is always dropped at the same spot.

These errors were often made due to the lack of concentration and reflexes. The knowledge of the existence of these errors helped me redo certain parts in order to reduce errors.

4.2 Limitations

Equipment

The degree of precision on all equipments was limited ther eby reducing for the extent of error. I therefore calculated percentage error and the add ed or subtracted that from the determined value.

In order to find the percentage error I used the formulae:

$$percentage\ error = \pm\frac{error\ range}{actual\ measure\ ment} \times 100\%$$

If $a = \frac{x}{y}$ then in order to find percentage error for 'a' you add the percentage error of 'x' with the percentage error of 'y'.

Therefore:

$$\%error\ of\ a = \%error\ of\ x + \%\ error\ of\ y$$

- Limited accuracy of the meter rule. When you measure an object of length 20.00cm (as is the measurement used for the distance through which the ball bearing travels), it could be anywhere in between 20.05cm and 19.05cm. This is due to the limited accuracy of the meter rule. Therefore while conducting experiment we allow for a margin of ±0.5mm. Therefore to calculate percentage error $\pm\frac{0.05\times100}{20} = \pm0.25\%$. Thus when considering to measure the length we say 20cm ±0.25%.

- Limited accuracy of the timer. When the ball takes 1.04 seconds to travel through 20cm the time could be anywhere between 1.035s or 1.045s therefore we say the time is 1.04 ± 0.005s. Therefore percentage error $\pm\frac{0.005\times100}{1.04} = \pm0.48\%$.

Temperature (□C)	Average time (s)	Percentage error (± %)
-10	87.29	0.01
-9	52.21	0.01
-8	35.46	0.01
-5	29.67	0.02
0	17.84	0.03
9	5.49	0.09
10	4.9	0.10
15	4.44	0.11
20	2.45	0.20
25	1.93	0.26
30	0.81	0.62
35	0.65	0.77
40	0.52	0.96
45	0.44	1.14
50	0.35	1.43
55	0.28	1.79

- Since $velocity = \frac{distance}{time}$, therefore :

Percentage error for velocity= percentage error for distance+ percentage error for time

Temperature	% error for	% error for	% error for

(□C)	time (± %)	distance (± %)	velocity (± %)
-10	0.01	0.25	0.26
-9	0.01	0.25	0.26
-8	0.01	0.25	0.26
-5	0.02	0.25	0.27
0	0.03	0.25	0.28
9	0.09	0.25	0.34
10	0.10	0.25	0.35
15	0.11	0.25	0.36
20	0.20	0.25	0.45
25	0.26	0.25	0.51
30	0.62	0.25	0.87
35	0.77	0.25	1.02
40	0.96	0.25	1.21
45	1.14	0.25	1.39
50	1.43	0.25	1.68
55	1.79	0.25	2.04

- Limited accuracy of weighing scales. If the mass of the ball is 0.88g , as it is the case in this experiment then it could either be 0.875 or 0.885g, this also causes the weighing scale to fluctuate between two values. Therefore to incorporate a margin for error of ±0.005g the percentage error $=\pm\frac{0.005}{0.88}\times 100 = 0.57\%$
- Limitation of the micrometer only allows you to take readings up to a degree of 0.001cm. during the course of my experiment the radius was 0.3005cm with an error rating of ±0.0005cm. therefore percentage error $=\pm\frac{0.0005}{0.3005}\times 100 = \pm 0.17\%$

- Percentage error in density of glycerol is due to the weighing scale , since the densities are calculated on the specific density bottle which relies on the weighing scale for its values. Therefore % error of density is ±0.005

25	1.254	0.40
30	1.253	0.40
35	1.251	0.40
40	1.246	0.40
45	1.244	0.40
50	1.242	0.40
55	1.236	0.40
0	1.264	0.40
9	1.262	0.40
10	1.26	0.40
15	1.259	0.40
20	1.258	0.40

Percentage error for volume of the ball depends on the micrometer. In order to find the volume of the ball you only need to find the radius of the ball. Therefore the error rating on the volume of the ball will be dependent on the micrometer which is used to measure the radius of the ball. % error

$$= \pm \frac{0.0005}{0.1336} \times 100 = 0.44 \pm \%$$

- Since upthrust is the weight of the liquid disp laced is
  $weight\ of\ glycerol\ displaced = density\ of\ glycerol\ \times volume\ of\ ball\ \times g$
  Therefore % error of upthrust is the sum of percentage errors of density and volume. The percentage errors in the density and volume have already been found therefore %error of upthrust is:

Temperature (□C)	%error for volume (±%)	% error density (±%)	%error for upthrust (±%)
-10	0.44	0.39	0.83
-9	0.44	0.39	0.83
-8	0.44	0.39	0.83
-5	0.44	0.40	0.84
0	0.44	0.40	0.84
9	0.44	0.40	0.84
10	0.44	0.40	0.84
15	0.44	0.40	0.84
20	0.44	0.40	0.84
25	0.44	0.40	0.84
30	0.44	0.40	0.84
35	0.44	0.40	0.84
40	0.44	0.40	0.84

45	0.44	0.40	0.84
50	0.44	0.40	0.84
55	0.44	0.40	0.84

- Therefore total error rating for viscosity is %error of upthrust + %error of velocity + %error of radius + %error of weight

Temperature	%error for upthrust	% error for velocity	%error for radius	%error for weight	%error for viscosity
-10	0.83	0.26	0.17	0.57	1.83
-9	0.83	0.26	0.17	0.57	1.83
-8	0.83	0.26	0.17	0.57	1.84
-5	0.84	0.27	0.17	0.57	1.84
0	0.84	0.28	0.17	0.57	1.85
9	0.84	0.34	0.17	0.57	1.92
10	0.84	0.35	0.17	0.57	1.93
15	0.84	0.36	0.17	0.57	1.94
20	0.84	0.45	0.17	0.57	2.03
25	0.84	0.51	0.17	0.57	2.09
30	0.84	0.87	0.17	0.57	2.45
35	0.84	1.02	0.17	0.57	2.60
40	0.84	1.21	0.17	0.57	2.79
45	0.84	1.39	0.17	0.57	2.97
50	0.84	1.68	0.17	0.57	3.26
55	0.84	2.04	0.17	0.57	3.62

Human Reflexes

There is nothing much that could be done about the accuracy of conducting the experiment by the person doing it. The reflex rates of individuals vary from one another. The better the reflexes the more accurate the result. It is therefore essential that to be relaxed while conducting the experiment as it is then that reflex es works best. There is no specific degree of uncertainty that can be associated with human incapability's to make accurate measurements. However the human eye is very accurate and precise and even the best of scientists rely on them to conduct major experiments.

4.3 Predicting the Equation for a Curve

The data points on the graph were eyeballed to see what kind of an equation would generate a line that is the best fit. I found that the viscosity temperature curve is exponential in nature. The curve is also negatively sloped therefore my concluded that the equation for the curve should be $y = e^{-x}$

Where y is the viscosity

Where x is the temperature

Where e is Napier's constant

$y = e^{-x}$ is an equation for a curve. If we take the natural log of both sides of the equation for a curve we obtain an equation for a straight line with a negative slope because x is negative. This follows the concept of natural logging of a geometric series to obtain an arithm etic series.

Therefore :

$y = e^{-x}$

$lny = lne^{-x}$(Natural logging both sides)

$lny = -x(lne = log_e e = 1)$

If we draw a graph for the natural log of y plotted against the temperature and we get a negative slope of 1 we can prove that that the equation for th e curve is $y = e^{-x}$, which will then help us obtain other values for viscosity at different temperatures with having to conduct the actual experiment.

temperature (celcius)	Viscosity (P) poise	ln viscosity
-10	556.490643	6.321650357
-9	332.900243	5.807842874
-8	226.1341671	5.421128483
-5	189.2688055	5.243168256
0	113.8212497	4.734629232
9	35.03763807	3.556422857
10	31.28185471	3.443038208
15	28.34956097	3.344611544
20	15.64575029	2.750199333
25	12.3326182	2.512247639
30	5.176662932	1.644160627
35	4.155391784	1.424406716
40	3.326872536	1.202032684
45	2.815912152	1.035286242
50	2.240619112	0.806752217
55	1.794148868	0.584530741

REFER TO APPENDIX – B FOR THE NATURAL LOG OF VISCOSITY AGAINST TEMPERATURE GRAPH

From the graph although a best fit line is drawn it does not lead to very conclusive results, due to the fact that the graph is hand drawn and therefore not very accurate.

I therefore calculate the correlation coefficient to see the extent to which my prediction is true. In order to find the correlation coefficient I need to find the covariance and then the standard deviation.

Covariance

$$s_{XY} = \frac{\sum_{i=1}^{n}[X_i - \bar{X}][Y_i - \bar{Y}]}{n-1}$$

Where

s_{XY} is the covariance between x(temperature) and y(natural log of viscosity)
X_i is the value of temperature from each trial
X is the mean of all temperature values
Y_i is the value of ln viscosity for each corresponding temperature
Y is the mean of all viscosity values
n is the number of trials

Standard Deviation

$$S_X = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

Where

S_x is the standard deviation of x(temperature)

N is number of trials

x_i value of temperature in each trial

x is the temperature mean of all trials

$$S_y = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y - \bar{y})^2}$$

Where

S_y is the standard deviation of x(temperature)

N is number of trials

y_i value of temperature in each trial

y is the temperature mean of all trials

Correlation Coefficient

$$r_{XY} = \frac{s_{XY}}{s_X s_Y}$$

Where

r_{xy} is the correlation coefficient of x and y

s_{xy} is the covariance

s_x is the standard deviation of x

s_y is the standard deviation of y

Correlation coefficient has a value between +1 to -1. Where +1 signifies perfect correlation that moves in the same direction i.e. as one value goes up the second value also goes up; -1 signifies perfect correlation that moves in opposite direction s i.e. as one value goes up the other value goes down; 0 signifies no correlation; a value of +0.5 or above or – 0.5 or below is acknowledged as being statistically significant. The value of correlation coefficient worked out from the results of my experiment yielded a value of -0.98. this signifies a very high negative relationship between x and y i.e. temperature and viscosity.

5 Conclusion

In this document I have reported on an experiment that investigated the relationship between temperature and viscosity. In it I have:

1. Explained the term viscosity and its significance.
2. Shown how viscosity is affected by temperature.
3. Introduced stokes law and showed how viscosity can be calculated from terminal velocity, upthrust and weight.
4. Shown that the relationship between temperature and viscosity is exponential.