The Specific Heat Capacity of Aluminium

Aim:
The aim of my investigation is to determine the specific heat capacity of aluminium.

Theory:
Specific heat capacity is the amount of energy required to raise the temperature of 1kg of mass by 1degree Celsius.[1] In order to calculate the specific heat capacity heat capacity (c) of aluminium I can use the equation, $\triangle$ H=mc$\triangle$T [2]
Therefore c=$\dfrac{\triangle H}{m\triangle T}$

I can measure the mass of the aluminium, (m), and the change in temperature of the block, ($\triangle$T), however the energy change, ($\triangle$H), is hard to measure. Another equation I can use to calculate $\triangle$H is the equation $\triangle$ E=ItV [3]. I can measure the energy supply using an electrical heater and recording the current the time and the voltage. Using the first law of thermodynamics or conservation of energy $\triangle$E=$\triangle$H. Therefore ItV=mc$\triangle$T. Using this knowledge I can design the basic circuit required to record the necessary measurements.

The aluminium block has two holes one containing a heat filament and one containing a thermometer. In order to try and measure the energy from the heating filament entering the block I need to prevent as much heat being lost into the environment as possible. Heat can escape in three ways, by convection, conduction and radiation. 'Convection involves the bulk motion of a fluid (liquid or gas) and is usually caused by hot fluid (being less dense) rising and displacing cold fluids. Radiation involves the emission and absorption of electromagnetic radiation. Conduction takes place in solids and in fluids, regardless of any bulk motion of the fluid.'[4] Conduction, like convection, requires a temperature difference to be established within the material, which conducts. In order to overcome the conduction the conduction and radiation from the aluminium I will lag the block with polystyrene to prevent conduction and convection and also silver foil to prevent radiation.

The polystyrene contains air, which is a very poor conductor, the air is trapped and convection can therefore not occur.

The temperature difference between the heating filament and aluminium determines the rate of energy transferred from the heating filament to the block. The apparatus reach equilibrium when both are the same temperature. When the heating filament is placed in contact with the cooler aluminium block the heat will flow towards the cooler object i.e. the aluminium block. This is thermal conduction. Aluminium is made up of a crystalline structure in which the positive metallic ions form a three dimensional lattice. Within the spaces provided by the lattice there exists a sea of delocalised electrons, and these outer electrons are therefore able to move throughout the lattice. The mechanism responsible for heat flow depends on coupling between adjacent molecules. The atoms in a solid have vibrated kinetic energy. At a hot region within the solid the vibrational energy is high. If there is another region where the vibrational energy is lower, then heat transfer can take place and is therefore a good conductor of heat. How much heat flows depends on additional factors e.g. time, initial temperature of the heating filament and block etc. It is never possible for the whole block of aluminium to reach the same temperature as the heating filament. When the temperature of the aluminium has stopped rising it is said to be in a steady state and the system is in equilibrium. The final temperature achieved at different points within the aluminium will depend on how the block is lagged. If the heat escapes through the sides then the greater the temperature of the block, the greater the temperature gradient and therefore the more heat is lost. If perfect heating insulation is achieved then no heat escapes through the sides and eventually the temperature in the aluminium block will be the same at any point. 'In the steady state it is found experimentally that the rate of flow of heat, Q/t, depends on the material of the block and is proportional to the cross-sectional area of the material.'[4] Because of this in my investigation I will try to prevent as much heat loss as possible by lagging the aluminium with polystyrene or bubble rap which will reduce convection and conduction. I will also use aluminium foil lagging to reduce heat loss through radiation.

Trial Run:
Apparatus;
➢ Voltmeter (recorded to 2d.p.)
➢ Ammeter (recorded to 2d.p.)
➢ Thermometer (recorded to the nearest half degree)
➢ Aluminium block
➢ Heat filament
➢ Connective wires
➢ Stop clock (recorded to the nearest second)
➢ Power pack
➢ Polystyrene
➢ Aluminium foil
The errors caused by some of these apparatus are calculated later in this investigation.

In order to calculate $\triangle$ E, which is equal to ItV, I will measure the current (I) in amps with an ammeter connected in series, the voltage (V) in volts with a voltmeter connected in parallel and the time (t) in seconds with a stop clock. As c (specific heat capacity)=ItV/m$\triangle$ T, m is the mass of the aluminium block which I weighed and found to be 1000.3g, I must therefore also measure the temperature T in degrees C with a thermometer so the change in temperature can be determined.

Method: (*Trial Run)*

♦ First I lagged the aluminium block with polystyrene and aluminium foil to reduce heat loss by convection, conduction and radiation.
♦ Connect circuit as shown in the above diagram.
♦ Record the initial temperature, current and voltage at time zero as soon as the power pack is switched on.
♦ Record the temperature, current and voltage every minute for fifteen minutes.
Switch the power pack off and continue recording the temperature every minute for a further fifteen minutes. This was to determine whether the insulation was sufficient or whether some heat was actually being lost into the surroundings.

Safety:

▪ Do not touch the heated filament, as this is very hot.
▪ Do not touch the aluminium block when the experiment is in operation as this to can also be hot.
▪ Once the aluminium has cooled, to check whether the temperature is cool enough for the object to be moved use the back of your hand.
▪ Be careful with the electrics.

After my trial run and analysing my results it was clear that the insulation around the aluminium was not sufficient to prevent heat loss to the surroundings as the temperature decreased by 4 ^{0}C. I will therefore add more insulation around the aluminium block and also around the top of the heat filament, which is not submerged with in the block. I also noticed that the temperature increased by 4 C once the power pack was switched off. The heat is therefore not being transferred from the aluminium block to the thermometer efficiently and quickly. To overcome this I will place oil in the hole surrounding the thermometer as the oil is a better conductor than the air, as its molecules are closer together and the heat is therefore more easily transferred to the thermometer reducing the time in which the maximum temperature is reached after the power pack is switched off.

In my actual method I will only record the temperature for between 5-10 minutes with the powerpack on and then off. This is because the temperatures reached over a longer period of time such as 15 minutes as used in my trial run produced a maximum temperature of 63 C. At temperatures as great as this there is a large temperature gradient between the block and the air, because of this a lot of heat is lost into the atmosphere producing less reliable results and I will therefore record the time and temperature for a shorter time as the final temperature will therefore be low, the temperature gradient lower and therefore less heat will be lost.

Method: *(Actual)*
Apparatus,
- Voltmeter $\pm$ 0.01 volts
- Ammeter $\pm$ 0.01 amps
- Thermometer $\pm$ 0.5 degrees
- Aluminium block
- Heat filament
- Connective wires
- Stop clock $\pm$ 1/100th of a second
- Power pack
- Polystyrene
- Aluminium foil

I chose to use these apparatus, as they were the most accurate instruments that were available in school. I used a digital voltmeter and ammeter rather than an analogue meter, as this will reduce the human error involved. The stop clock used measured to the nearest hundredth of a second, however the time it took to measure the ammeter and voltmeter readings effected the accuracy of the time values, and I felt it was not necessary to measure time this accurately due to the large human error involved when recording it. I therefore recorded the values of time to the nearest second.

- First I added extra lagging to my aluminium block making sure that the top of the heating filament and thermometer hole is covered to prevent heat loss.
- Connect circuit as shown in the diagram above.
- Record the initial temperature, current and voltage at time zero as soon as the power pack is switched on.
- Record the temperature, current and voltage every minute for the required length of time. I decided to perform the experiment three times so I would have repeated sets of results, which I could compare.
- I chose to record the temperature, voltage and current for 10 minutes starting at room temperature.
- Switch the power pack off and continue recording the temperature, current and voltage for a further 10 minutes.
- Remove the lagging from the aluminium and allow to cool
- Once cooled repeat the experiment starting at room temperature performing the experiment for only five minutes with the power pack on and then a further five minutes with the power-pack and hence heating filament off. I decided to record the change in temperature for a shorter length of time, to see whether the final temperature reached would have an effect of the accuracy of the results, as a shorter time would produce a lower final temperature and also a smaller change in temperature.
- Finally I repeated the experiment for five minutes once again however this time starting at a higher initial temperature greater than room temperature. The record the temperature for a following 5 minutes with the heating filament off.

In this investigation there are several sources of error such as the digital ammeter and voltmeter, the thermometer, the stop clock and human error when reading all three instruments.

The ammeter and voltmeter both record to two decimal places however the values did fluctuate by approximately 0.04, this produces a relatively small source of error as shown below.

$$\text{Ammeter,} \quad \%\text{error} = \frac{0.04}{3.34} \times 100$$
$$= 1\%$$

$$\text{Voltmeter,} \quad \%\text{error} = \frac{0.04}{12.89} \times 100$$
$$= 0.3\%$$

Because these were very small source of error I did not feel it necessary to use an analogue meter which would record to three decimal places, as this would have produced little effect on the final results.

Laura Cope 13H

The thermometer I used was one, which could record to the nearest half degree. I was unable to use a more accurate thermometer, as these were the best in school.

$$\text{Thermometer, \%error} = \frac{0.5 \times 100}{20}$$
$$= 3\%$$

This is a slightly larger source of error and along with human error of measurement could result or is used to explain any inaccurate results.

The stop clock recorded to the nearest second, the largest error will occur at the lowest time, which is when the first recordings take place after 60 seconds.

$$\text{Stop clock, \%error} = \frac{1 \times 100}{60}$$
$$= 2\%$$

This is also quite a small source of error.
However only the total time in actually used in the calculation $\triangle$ E = ItV. Therefore the error caused by the stop clock is even smaller.

$$\text{Stop clock, \%error} = \frac{1 \times 100}{300}$$
$$= 0.3\%$$

The largest source of error involved in the investigation is due to the time taken to record the readings of the voltmeter, ammeter, thermometer and stop clock which are all supposed to be recorded simultaneously, where as in fact there could be up to a three second delay as to the actual time a reading could have been taken, as three seconds was approximately the time it took to record all four results. Another source of inaccuracy was the assumption I made in performing the experiment that the reading of the thermometer was the temperature of the whole block. This was not the case as the temperature of the centre of the aluminium block, which was near the heating filament, would have been greater than that of the edge of the block. The thermometer was placed half way between the centre and edge of the block, however this does not produce a value for the average temperature of the block as the temperature does not spread out evenly.

Laura Cope 13H

Analysis:

In order to the calculate the specific hat capacity of aluminium the equation, 'ItV=m$\triangle$ T'[5] must be used. To find the specific heat capacity (c) the equation can be rearranged into the form, c= $\frac{ItV}{m\triangle T}$

Using my trial run results in which,
Average I=4.01amps
Average V=0.45 volts
t=900 seconds
Therefore $\triangle$ E=ItV=37700J

m=1kg
$\triangle$T=36°C

Therefore c=$\frac{37700}{(1\times36)}$
=1047 Jkg^{-1} $^{\circ}$C^{-1}

From research in a variety of sources I have discovered that the actual value for the specific heat capacity of aluminium is 880 [6] or 900 [7] Jkg^{-1} $^{\circ}$C^{-1}

Due to the difference between my results from my trial run and the book values, I modified my method reducing the time in which the block was heated for, so that the final temperature of the block would be lower and therefore the heat gradient between the block and the air lower which should reduce the amount of heat lost into the atmosphere, this should result in more accurate results.

I calculated my other results using formulas in a Microsoft spread sheet.

From the graphs there is a clear trend that as the time in which the block is heated increases expectedly the temperature of the block increases. Once the heating source is switched off there seems to be a continuation in the heating of the block for approximately 3 degrees. This maximum temperature was maintained for about a minute, and then there was a slight decrease in temperature by approximately 1 degree, excluding the trial run, which there was a drop in temperature of four degrees. Due to this drop in temperature more lagging was added to the block and heating source for the remaining experiments.

Studying results table three which was when the aluminium was heated for 10 minutes and timed for a further 10 minutes in which the heating source was switched off, it can be seen that the specific heat capacity of the aluminium block was 922 Jkg^{-1} $^{\circ}$C^{-1}. This value is very near the text book values for the specific heat capacity. I was surprised to find that this set of readings were nearer to the actual value than the

Laura Cope 13H

readings shown in results table 1, which was when the aluminium was only heated for five minutes. I would have predicted that these results would have been the nearest to the actual reading as the final temperature reached would have been lower than that of any of the other sets of results, the temperature gradient would therefore be smaller between the block and the air, therefore convection would be less likely to occur and heat would not be lost producing more accurate results.

This was not the case, however it can be seen that for results number 1 there is in fact no drop in temperature once the heating source was switched off which was what I would have predicted. Therefore the inaccuracy of these results was not due to the loss of heat and is more likely to be the result of a time delay ie the time taken for the heat from the heating filament to be transferred into the aluminium block and then into the thermometer. That is why the maximum temperature recorded is after the heating filament is switched off. Only 10 readings were taken in total, where as for results 3, 20 readings were taken which is double that of results1. Fewer readings were taken recording results one than for results three, this may have resulted in less reliable results. However the results are likely to be more accurate as a lower final temperature is reached and therefore the heat gradient is less and less heat will therefore be lost.

For results one, if the major source of error was the time it took to record the measurement, which took about 3 seconds, I can calculate the least and greatest values for the specific heat capacity.

The range for the value of t would be 297secs-303secs
Therefore ItV=12100-12300
Using the maximum and minimum values for $\triangle$E, I can calculate the range of the specific heat capacity which could be cause by the maximum and minimum values of the error involved in recording the values from the apparatus e.g. the ammeter, voltmeter and thermometer.

min c = $\dfrac{12100}{(m\triangle T)=10}$ max c = $\dfrac{12300}{10}$

min c = $1210Jkg^{-1}\,{}^{o}C^{-1}$ max c = $1230Jkg^{-1}\,{}^{o}C^{-1}$

Therefore the error caused by the time taken to record the results can result in an approximate difference of $20Jkg^{-1}\,{}^{o}C^{-1}$. However the range 1210-1230 does not include the actual value for the specific heat capacity of aluminium which is approximately $900Jkg^{-1}\,{}^{o}C^{-1}$. There must therefore be other reasons as to why these results are not accurate, I think this may be due to a lack of readings. Only 10 readings were taken in total, where as for results 3, 20 readings were taken which is double that of results1. It may also have been due to the time delay on the temperature.

The lack of number of readings would also explain the inaccuracy of the results recorded in table 2, which had 12 readings. These results were the least accurate which is what I would have expected because the initial temperature was a lot greater and hence the final temperature was also a lot greater, the temperature gradient was therefore quite large between the block and the air and therefore the convection current would be greater and more heat would be lost. This means that the change in

$\triangle$

temperature will be smaller and therefore using the equation c=ItV/m Δ T, the value calculated for the specific heat capacity will therefore be falsely high and may explain why the calculated value was 1290Jkg^{-1} ^{0}C^{-1} which was the highest value and therefore the least accurate of all of my results.

All of my results showed an increase in temperature shown on the thermometer once the heating source was switched off. This suggests that there is a delay between the time when the heat reaches the block and when it reaches the thermometer. Heat is transferred relatively slowly from the heating filament to the aluminium block through convection current within the air, which is in the space between the filament and the block. Conduction then takes place, which transfers the heat through out the block . The nearer the thermometer is to the centre of the block the faster the heat will be transferred, and the greater the change in temperature readings. This will mean that the overall result for the specific heat capacity will be less. This may make my results nearer the book values. Oil was placed in the hole in the aluminium block, which contained the thermometer, to speed up convection current between the block and the thermometer so that the heat is transferred quicker. Convection occurs quicker in oil due to the fact that the particles in the oil are closer together and it therefore takes less time for the heat to reach the desired location. Conduction can also occur in the liquid as long as there is a temperature difference. When two particles collide and one has more energy than the other does the particle with greater energy transfers some of this energy in the form of heat to the other particle.

From looking at my result tables I can estimate the time delay from which the heat from the heating filament reaches the thermometer. I can do this by finding the time taken for the maximum temperature to be reached, once the heating filament was switched off. These results are also shown on the graphs. For my trial run the time delay was 3 minutes, (this was performed without any oil in the hole with the thermometer.) During this time there was a temperature rise of 4 degrees. If this temperature rise is taken into consideration when calculating the specific heat capacity of the metal, and is added onto the change in temperature, a more accurate value for the specific heat capacity should be found.

Trial Run-   c=ItV/mΔ T
                 =4.01x900x10.45/(1x(36+4))
                c=943Jkg^{-1}C^{-1}

This value is nearer the book value of the specific heat capacity of aluminium.

For result 1,2 & 3 the time delay should be less as the oil was added around the thermometer to aid conduction and convection. Looking at the tables and graphs it can be seen that results 1 and 2 have a time delay of 2 minutes and results 3 only a time delay of 1 minute. Including the value for the increase in temperature during this time the new values for the specific heating capacities of the aluminium can be found.

Results 1-   c=3.31x300x12.30/(1x(10+4))
                 =870Jkg^{-1}C^{-1}

Results 2-   c=3.34x360x12.89/(1x(12+2.5))
                 =1070Jkg $^{-1}$C^{-1}

Results 3-   c=3.30x600x13.5/(1x(29+2))
             =862Jkg $^{-1}$C^{-1}

As you can see these results are lower and are nearer to the actual value of the specific heating capacity (s.h.c.) of aluminium. However now results one and three are now lower than that of the book values. The reasoning behind this is that the thermometer is too close to the centre of the aluminium and therefore a higher temperature of the aluminium is being recorded by the thermometer rather than the average temperature of the whole block. Previously the time delay was compensating for this fault.

From studying the graphs a rough guide to the specific heat capacity of a substance can be found. The specific heat capacity is related to the gradient of the sloping section of the graphs. The steeper the gradient, the faster the substance heats up, and hence the lower its specific heat capacity must be. Results 3 should the lowest specific heat capacity which was nearest the book value the gradient of this graph was 3.30, where as the Results 2 which produced the value for the largest s.h.c produced a graph with a gradient of 2.33.

Evaluation:
The apparatus I used for this experiment were very suitable as they were the most accurate instruments we had in school. Due to their accuracy the percentage errors they caused were insignificant and did not result in the inaccuracy of any of the results. The method was not the most efficient as it was very difficult to record the current the voltage the thermometer in one second, and therefore resulted in quite a large source of error. The experiment could have been improved if we had worked in groups and recorded different things so that all the results were recorded simultaneously.

The mass (m) used in the equations does not include the weight of the thermometer or the heated filament, as these are not made of aluminium. The aluminium foil used for insulation was also not included in the mass of the aluminium block however the weight of the foil could have been included as all aluminium has the same specific heat capacity. As previously stated the thermometer and heating filament are not included in the mass, this may have some effect on the results as both of these instruments take in or contain some of the heat, which reduces the heat within the aluminium block its self.

There were no real anomalous results recorded. However experimental determinations of specific heat capacities usually involve some loss of heat to the surroundings by convection and conduction. There is also some loss of heat due to radiation, which is more significant at high temperatures; this can be reduced by using polished surfaces. A way of reducing the effect of the heat losses, which remain, is to apply a cooling correction.

In this experiment the temperature was recorded both during heating and after the heating as discontinued. The temperature was shown to vary in results two and three once the heat was discontinued, and the shapes of the graphs are as below.

It can be shown that,
$$\triangle \theta = A/A' \triangle \theta' \quad (8)$$

Measuring $\triangle \theta'$ and the areas A and A' enables the correction $\triangle \theta$) to be found.

The theory behind the cooling correction is based on Newton's Law of cooling. This law states that the 'rate of loss of heat of a body is proportional to the difference in temperature between the body and its surroundings, i.e.
(Rate of loss of heat to surroundings) α (Excess temperature)
Or
(Rate of loss of heat to surroundings) $= k (\theta - \theta_o)$
This applies when a body is cooling under conditions of forced convection.
Where θ = Temperature
θ_o = Temperature of surroundings
k = a constant of proportionality whose value depends on both the nature and the area of the body's surface.'[9]

Provided the excess temperature is not greater than about 30°C, this law can be taken to be a good approximation for cooling under condition of natural convection. For higher excess temperatures than this the Five-Fourths Power Law should be used. Radiation in particular is affected by the Five- Fourths Power Law.

The theory of the cooling correction is that if Newton's law of cooling applies, the rate of loss of heat to the surroundings dQ/dt, both heating and during cooling is given by
dQ/dt $= k (\theta - \theta_o)$ [10]

Where k is a constant of proportionality, and the total loss of heat Q, is the interval between t=0 and t=t_1 is given by

$$Q=\int_o^{t1} \frac{dQ}{dt}\, dt \qquad =\int_o^{t1} k(\theta-\theta_o)dt$$

i.e. Q= k x Area A
Similarly, the loss of heat, Q', between t=t_1 and t=t_2 is given by Q' = k x Area A

$$\text{Therefore } \frac{Q}{Q'} = \frac{\text{Area A}}{\text{Area A'}}$$

But, Q= c$\triangle\theta$ and Q'= c$\triangle\theta$' where c is the heat capacity of the body, and therefore

$$\frac{\triangle\theta}{\triangle\theta'} = \frac{A}{A'}$$

i.e. $\triangle\theta = \dfrac{A\triangle\theta'}{A'}$

This method is based on the assumption that the rate of loss of heat is directly proportional to the temperature difference between the body and its surroundings.

On my graph showing my results for my trial run I can calculate the cooling correction using the method above,
Where $\triangle\theta$ = x, and $\triangle\theta'$=y
Therefore x=Ay/A'
   x=12.5x3/12.5
   x=3degrees
The maximum temperature reached during the experiment including the cooling correction is 63+3=66degrees
$\triangle$T would be 39degrees i.e. 59+3 -23.
Therefore the new value for the s.h.c. of aluminium if not heat was lost into the environment would be c=ItV/m$\triangle$T
    =4.01X900X10.45/39
    =967Jkg^{-1}C
this value is a lot nearer the book value of the aluminium, that the initial calculations showed. This shows that a large percent error is due to the cooling of the aluminium. If the change in temperature originally was 36 degrees and including the cooling correction the temperatures would have been 3 degrees higher the percentage error initially caused by this was 3x100/36 = 8%.

Looking at results 1 I decided that there was no drop in temperature once the heating filament was switched off and therefore no heat was being lost during the experiment, there was therefore no need to do a cooling correction graph, and the inaccuracy of the s.h.c. must be due to other factors.

Results 2 and 3 both showed a slight drop in temperature once the filament was switched off. The value of x calculated for these results were 1.6 and 1.5degrees respectively. This means the maximum temperatures reached would have been for

results 2, 64degrees and for results 3, 52.5degrees. These produce vales for the s.h.c of aluminium to be;

Results 2- 1140Jkg^{-1}C^{-1}

Results 3- 876Jkg^{-1}C^{-1}

These values are both nearer the actual value of the aluminium. Results 3 show a value less than expected as it is lower than the actual book value this is because the thermometer is too close to the centre of the block and is therefore recording a higher temperature than that of the average of the block. Previously the loss of heat to the surroundings was compensating for this fault however including the cooling correction produces a larger value for the change in temperature and due to the equation c=ItV/m $\triangle$ T the s.h.c will be lower an ItV remains constant but is being divided by a larger value for the change in temperature.

Results 2 had a larger value for the cooling correction than graph 3 because the maximum temperature reached was higher and therefore the temperature gradient between the block and the air was greater and therefore more heat is likely to be lost into the surroundings. This explains why results 1 were not effected by heat loss to the environment as the final temperature was lower as the initial temperature was lower and the experiment was not undertaken for as long. The temperature gradient was less therefore no heat was lost.

A way to eliminate the need for a cooling correction altogether is to cool the aluminium to about 5 degrees below room temperature and the heat steadily to about 5 degrees above, the heat gained by the aluminium from the surrounding during its initial heating will be almost identical to the heat lost by the aluminium into the surrounding in the second half of the experiment. The cooling correction is therefore not necessary.

In this experiment the position of the thermometer is very important as the temperature varies throughout the block, the centre of the block being hotter than that of the edge of the block. However there was only one possible place in which the thermometer could be placed. An improvement to the experiment would be to vary the place which the thermometer was placed within the aluminium block and see how the results are affected. This could not be done in school, as the equipment was not available. Another improvement could be to use light gates instead of using stop clocks as this means that human reaction times are not involved and the results will therefore be more accurate.

To reduce the error caused by the time taken to read the stop clock thermometer, the voltmeter and the ammeter you could be ready looking at the thermometer as the required time is approaching and the read the temperature at the exact time as this is the result which changes most frequently and has the most influence on the results. The reading on the ammeter and voltmeter remain almost constant with slight fluctuation, however an average reading of these can be taken so a slight delay in reading these values will have little effect on the results.

Bibliography

- Advanced Physics-Tom Duncan

- A-level physics-Roger Muncaster
- Physics-J L Lewis & G E Foxcroft
- Basic Physics 1 and 2-David Sang
- A-level Physics, letts study guide-Kenn Dunn

References:

(1)Basic Physics 1 and 2- David Sang
(2)A-level Physics, letts study guide- Kenn Dunn
(3)Physics- J L Lewis & G E Foxcroft
(4)A- level physics- Roger Muncaster
(5)A-level physics, letts study guide
(6)Basic Physics 1 and 2 – David Sang
(7)Physics- J L Lewis & G E Foxcroft
(8),(9),(10)A-level physics- Roger Muncaster