The Efficiency of an Electric Motor

Aim: To investigate how the efficiency of an electric motor varies when it is lifting different weights.

Summary: I have investigated how the efficiency of an electric motor varies when it is lifting different weights. I found that the efficiency of my motor (using an input voltage of 4v) was maximum when it was lifting 500-800g weights. I also found that the efficiency of the motor depended on its internal resistance and friction.

I also used my results to estimate the internal resistance of the motor and I found it was about 0.5Ω

In my extension experiment I used the electric motor as a generator. I dropped a variety of weights from my pulley system and I measured the amount of energy produced using a joule meter. I found that the efficiency of the generator increased as the mass of the weight I dropped increased. The percentage efficiency of the generator also appeared to tend towards 14%.

Finally I discussed whether my experiment was time reversible. I decided that it was to an extent but not completely. I decided this since I only retrieved about 1-2% of the energy I used to lift the weight when I dropped the weight again, using the motor as a generator.

Experiment 1:

See Diagram1 for Apparatus and circuit diagram

Experimental Method:

I will use a 12v electric motor to lift a variety of weights a fixed height and I will measure the voltage and current in the motor coils. I will also measure the time taken to lift the masses.

How will I make my experiment accurate?

1. In my experiments I will keep all variables constant except the one I am investigating. I will vary the mass of the load but I will keep the input voltage to the motor and field coils constant and I will lift the load to the same height each time.
2. I will repeat each measurement in till I am satisfied that it is accurate and then I will use an average when I am analysing my results. I will also take a wide range of results to ensure I get a complete picture.
3. I will do a trial experiment to decide on appropriate values for the voltage in the motor and field coils. I will also need to decide on appropriate range of masses to test. I want the voltage in the motor coils to be large enough so that I can measure the current/voltage in the motor coils accurately with a 1-10 V/A meter however I want the motor to be able to lift a wide range of masses at this voltage.

Acknowledged Errors:

1. Friction in the pulley will reduce the efficiency of the motor .The pulleys are needed to reduce the torque the motor requires to lift the weights. By reducing the torque the motor can lift a wider range of weights. I have tried to reduce the friction in the pulleys by oiling them.
2. The radius of the cotton reel used to wind the string around the motor shaft increases as more string is wrapped round it. As a consequence the torque on the motor is increased. This error is unavoidable and I will attempt to correct for it by using an average value for the radius in my calculations.
3. The internal resistance of the power supply and the ammeter used in my experiment will affect the voltage across the motor. For this reason I will directly measure the voltage across the motor and I will not simply use the E.m.f of the power supply in my calculations.
4. The bottom pulley contributes to the weight of the load. It weighs 104.8 grams (error +/-0.1g)

<u>My results:</u>

Experiment1: Field coils voltage=9.88V, Motor Coil input voltage (as show on power pack)=4V, the height the mass was lifted=1.025 m (% error=0.9), g=9.8(Estimated error=1%)

I repeated each reading in till I got reliable results the value given in the table is the average value I recorded.

Mass (including pulley) in grams	**Average Voltage (V)**	**Average Current (A)**	**Average time taken to lift mass l.025m**
Estimated Error=+/- 1%	Estimated Error==+/- 0.05V	Estimated Error=+/-0.05A	Estimated Error==/- 0.3s
1304.8	1.03	2	75.72
1204.8	1.1	1.88	47.84
1104.8	1.15	1.8	40.97
1004.8	1.17	1.84	30.69
904.8	1.2	1.65	26.82
804.8	1.2	1.55	21.56
704.8	1.3	1.49	17.84
604.8	1.35	1.4	15.66
504.8	1.4	1.3	13.72
404.8	1.45	1.2	12.57
304.8	1.55	1.13	11
204.8	1.6	1.05	10.44

Experiment 2:

Although the voltage and current remained roughly constant while I was lifting the weights at a steady speed, they varied by as much as .3V/A. This variation was due factors such as the varying friction of the pulley system and it made taking accurate results difficult.

In my second experiment I am going to use a joule meter to measure the amount of energy given to the motor. The joule meter will take in account the fluctuations in voltage/current that I observed and therefore it should give more accurate results. This is assuming that the joule meter is accurate.

See Diagram 2 for circuit diagram

<u>Experimental Method:</u>

I will attach different masses to the pulley and I will measure how high they are lifted if 20J of electrical energy is given to the motor-As soon as the joule meter reads 20J I will stop the weight and measure the distance it has moved.
I have chosen this method since the joule meter I am using can only measure the number of joules received to the nearest 10J. In my experiments I was only using about 30-70 Joules and therefore the error in my results could be as high 33%.

However using the joule meter I can accurately tell when exactly 20J of energy has been used, and then I can then use the ruler to measure the height of the weight to the nearest millimetre. Using this method and assuming that the joule meter is accurate, I estimate the experimental error to be about 2-3%.

My results:

Motor coil voltage (as shown)=4V, Field Voltage=9.80

Mass (g) (inc pulley)	Voltage (V)	Height Lifted (Cm)	Height lifted Exp2 (Cm)	Average Height Lifted(Cm)	Average Time taken to lift weight (s)
Estimated Error=+/- 1%	Estimated Error==+/- 0.1V	Estimated Error =+/-0.5cm	Estimated Error =+/- 0.5cm	Estimated Error =+/- 0.5cm	Estimated Error=+/- 0.2s
904.8	1.9	59	59.5	59.25	8.15
954.8	1.87	54.2	53.9	54.05	8.05
1004.8	1.85	49	48.8	48.9	8.03
1054.8	1.83	44.4	44.2	44.3	7.8
1104.8	1.8	40	41	40.5	7.69
1154.8	1.8	37.3	36.1	36.7	7.45
1204.8	1.78	33	32.6	32.8	7.06
1254.8	1.79	29.7	30.6	30.15	7.95
1304.8	1.85	27.5	28	27.75	6.85
1354.8	1.79	25.1	24.7	24.9	6.67
1404.8	1.79	22.3	21.9	22.1	6.44
1454.8	1.77	20.4	19.8	20.1	6.33
1504.8	1.75	18.1	17.7	17.9	6.31
1554.8	1.73	15.7	16.8	16.25	6.25
1604.8	1.72	15.3	14	14.65	6.12
1654.8	1.7	13.6	13.5	13.55	6.23
1704.8	1.67	11.2	12	11.6	6.22

Testing the accuracy of the joule meter

Before I analyse the results from my experiment I will test the accuracy of joule meter.

See Diagram 3: For Diagram of Apparatus used

Exp**erimental Method:**

I will supply the joule meter with a constant voltage and I will time how long it takes to record energy of 10J. From this information I will be able to compare the energy I put in to the joule meter and the energy it recorded and I will be able to draw a calibration curve.

My Results:

Load=10.3Ω

Voltage (V)	Time for 10J
1.97	20.9
1.8	22.9
1.6	26.7
1.4	33.4
1.2	46.7
1	69.5
0.8	112.68
0.5	360.76
0.4	593.72

- I would have repeated my results for this experiment if I had more time

Analysing the results of the calibration experiment:

Voltage (V)	Time for 10J (s)	Power in (watts)	Power recorded (W)	Joules in	Joules recorded	% Error	Voltage squared
1.97	20.9	0.376786408	0.4784689	7.874835922	10	26.98677279	3.8809
1.8	22.9	0.314563107	0.436681223	7.203495146	10	38.82149981	3.24
1.6	26.7	0.248543689	0.374531835	6.636116505	10	50.69054307	2.56
1.4	33.4	0.190291262	0.299401198	6.355728155	10	57.33838446	1.96
1.2	46.7	0.139805825	0.214132762	6.528932039	10	53.16440638	1.44
1	69.5	0.097087379	0.143884892	6.747572816	10	48.20143885	1
0.8	112.68	0.062135922	0.088746894	7.001475728	10	42.8270323	0.64
0.5	360.76	0.024271845	0.027719259	8.75631068	10	14.20334849	0.25
0.4	593.72	0.015533981	0.016842956	9.222834951	10	8.426531025	0.16

This is how I calculated the above values:

Power in= V^2/R R=10.3Ω

Power recorded=10J/Time taken

Joules in=(Power in) *(time taken for 10J)

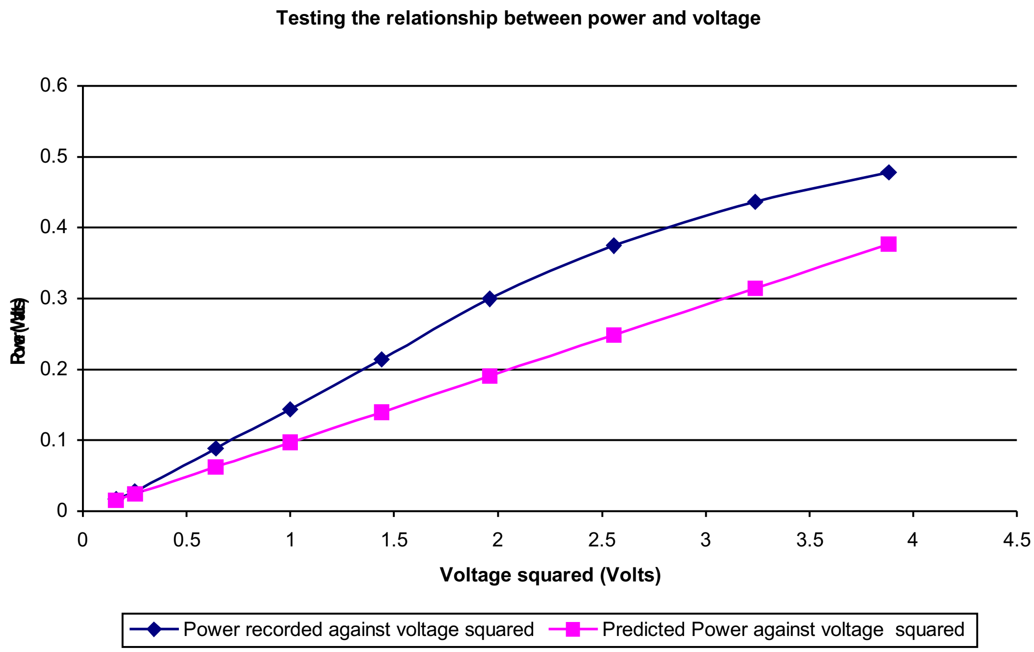
% Error=100(Joules recorded-Joules in)/Joules in

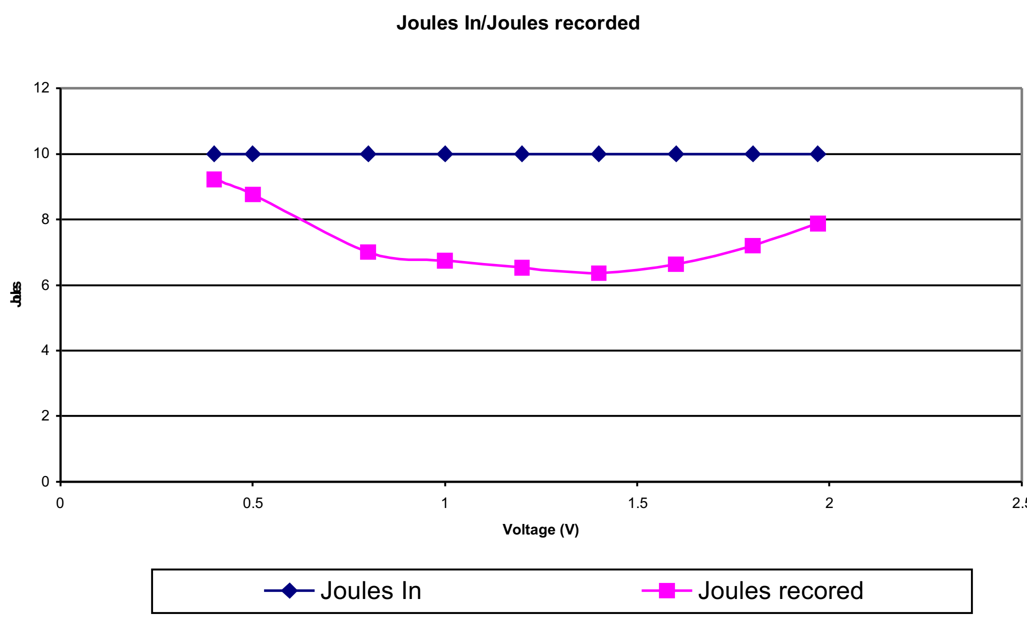
Is the power recorded equal to $\frac{V^2}{R}$?

If the joule meter is accurate the power it records will be equal to $\frac{V^2}{R}$. To test this I have plotted the power recorded against the voltage I recorded squared. This should give me a straight line in the form

$y = mx + c$ In which y=Power recorded, m=1/R, x=V^2, c=O since when V=0 P=0

I have also plotted a how the power should vary with respect to the voltage squared for use as a comparison. (see next page)



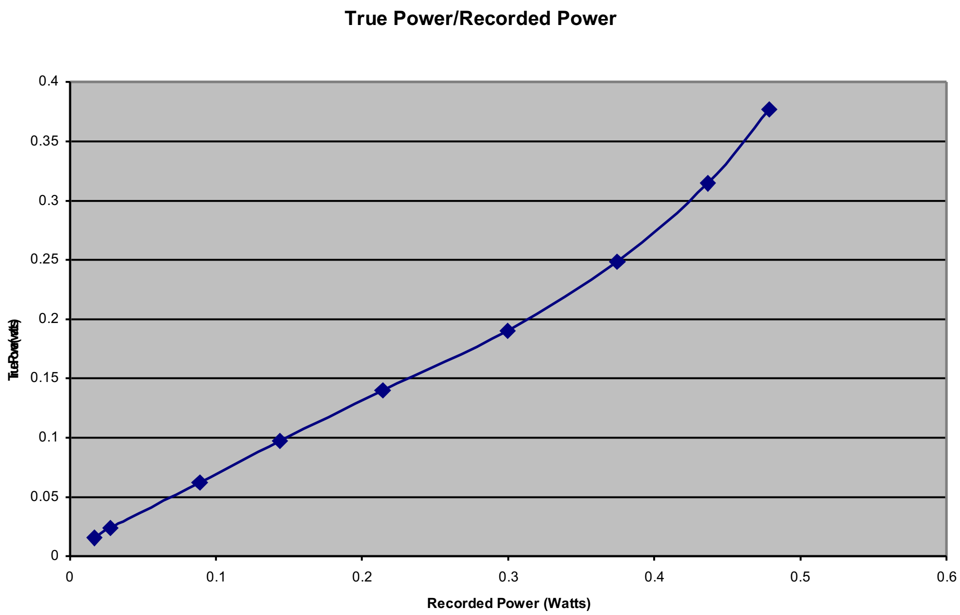


<u>Analysis of the graphs:</u>

The power recorded is roughly equal to the predicted power. The accuracy of the joule meter seems to vary with voltage (see graph 2); the joule meter is most accurate at very low voltages (0-0.5V) and it is least accurate at about 1-1.6V. This is unfortunate since these are the voltages that I have used in my experiments. The accuracy then appears to increase for voltages higher then 1.6V.

Since the accuracy of the joule meter varies predictably I have drawn a calibration curve for the joule meter (shown below). This graph will allow me to correct for errors caused by the inaccuracy of the joule meter when I analyse my results.

I have not had enough time to calibrate the joule meter using a wide range of voltages and energies and therefore my calibration curve is not as useful as it could have been.

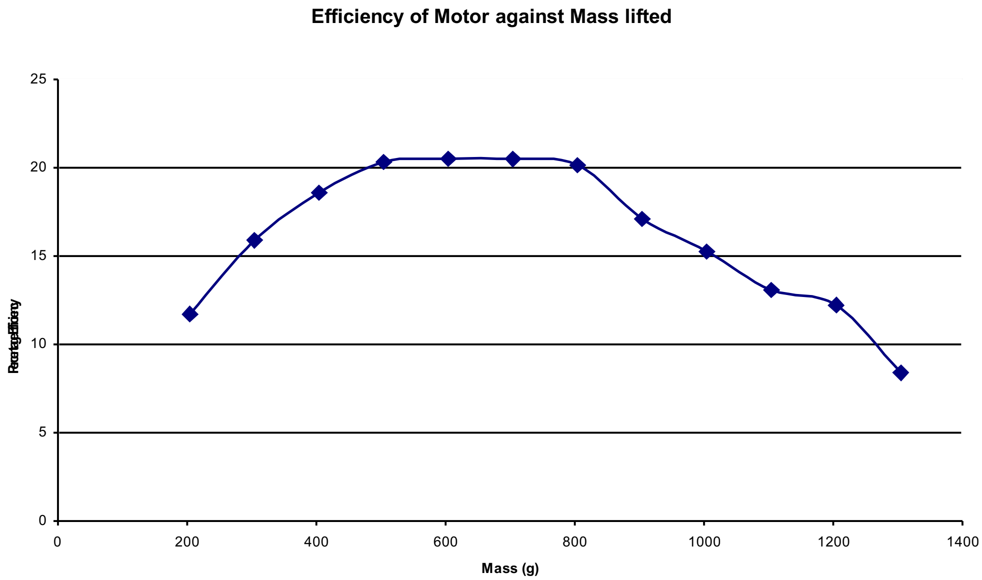


Analysing my Results for Experiment 1 and 2

Experiment 1:

%E=stands for percentage error and it applies to the previous column

Mass (g)	Voltage (V)	%E	Current (A)	%E	Time taken to lift mass l.025m	%E	Joules of Electrical energy used	%E	Work Done	%E	Efficiency of Motor	%E
Error=1%	Error= 0.05V		Error=+/- 0.05A		Estimated Error=+/- 0.3s					**=1+1+0.9**		
1304.8	1.03	4.85	2	2.5	75.72	0.396	155.98	7.75	13.106716	2.9	8.402645926	10.65056545
1204.8	1.1	4.55	1.88	2.66	47.84	0.627	98.93	7.83	12.102216	2.9	12.23272449	10.73211931
1104.8	1.15	4.35	1.8	2.78	40.97	0.732	84.80	7.86	11.097716	2.9	13.08571018	10.75784697
1004.8	1.17	4.27	1.84	2.72	30.69	0.978	66.07	7.97	10.093216	2.9	15.27668045	10.86841268
904.8	1.2	4.17	1.65	3.03	26.82	1.119	53.10	8.32	9.088716	2.9	17.11506565	11.21553793
804.8	1.2	4.17	1.55	3.23	21.56	1.391	40.10	8.78	8.084216	2.9	20.15933529	11.6839388
704.8	1.3	3.85	1.49	3.36	17.84	1.682	34.56	8.88	7.079716	2.9	20.48761318	11.78347289
604.8	1.35	3.7	1.4	3.57	15.66	1.916	29.59	9.19	6.075216	2.9	20.52618135	12.09084109
504.8	1.4	3.57	1.3	3.85	13.72	2.187	24.97	9.6	5.070716	2.9	20.30690738	12.50417134
404.8	1.45	3.45	1.2	4.17	12.57	2.387	21.87	10	4.066216	2.9	18.59113562	12.90157737
304.8	1.55	3.23	1.13	4.42	11	2.727	19.27	10.4	3.061716	2.9	15.89139698	13.27785794
204.8	1.6	3.13	1.05	4.76	10.44	2.874	17.54	10.8	2.057216	2.9	11.72924649	13.66046798



Explaining the graph:

In my experiment energy must be conserved, and it follows that the electrical energy I put in to the motor must equal the sum of the energy I get out.

If I first consider the system without friction: the equation below must be satisfied:

Electrical Energy In=(Energy lost in the internal resistance of the motor coils) +(Work done lifting the weight)

$IVt=I^2Rt+$(Work done lifting the weight) t=time, R=resistance of motor coils

The power used lifting the weight is equal to εI, ε is the back ε.m.f resulting from the fact that the motor coils are moving through flux in a magnetic field.

$IVt=I^2Rt+\varepsilon It$ [1]

If I now consider friction which I am assuming is constant:

$IVt=I^2Rt+\varepsilon It+$(Work done against friction)
$IVt=I^2Rt+\varepsilon It+FD$

Here F= frictional force D=distance mass has travelled

Before I can do any further analysis I must first calculate the internal resistance of the motor coils. In my analysis I am going to assume that the resistance is constant as this is a good enough approximation for calculations. In fact the resistance of the coils varies slightly with the speed and temperature of the motor.

<u>Estimating the resistance of the motor coils</u>

You can only measure the internal resistance of an electric motor when it in motion as a result of the effect of the commutator and other factors.

From my research I found out that for a motor

$\omega = \frac{V}{K} - \frac{R}{K^2}T$ ω=Angular velocity of motor shaft, K=motor constant, T=torque provided by motor, R=resistance of motor coils, V=voltage.

If I plot ω against T the value of ω at y intercept is equal to $\frac{V}{K}$ and the torque at the x intercept is equal to $\frac{KV}{R}$. Using my recorded values and the intercept values I will be able to calculate the internal resistance of the motor.

1) Finding an expression for ω:

- Average Circumference of cotton reel used to wind up string= 2π*(average radius of cotton reel)
  Average radius≈0.02m
  ⇒Average Circumference=0.04π
- Total Number of rotations of the motor shaft=Length of string wound up/Average Circumference
  =6.15/0.04π
- Number of rotations per second=Total No. of rotations/Time taken to lift weight
  $= \frac{153.75}{\pi t}$
- ω=No. of rotations of motor shaft per second*2π
  ω=307.5/t

2) Finding an expression for the torque of the motor: (ignoring friction)

Torque = Moment acting on the shaft
T=Force*Average Radius of Cotton reel

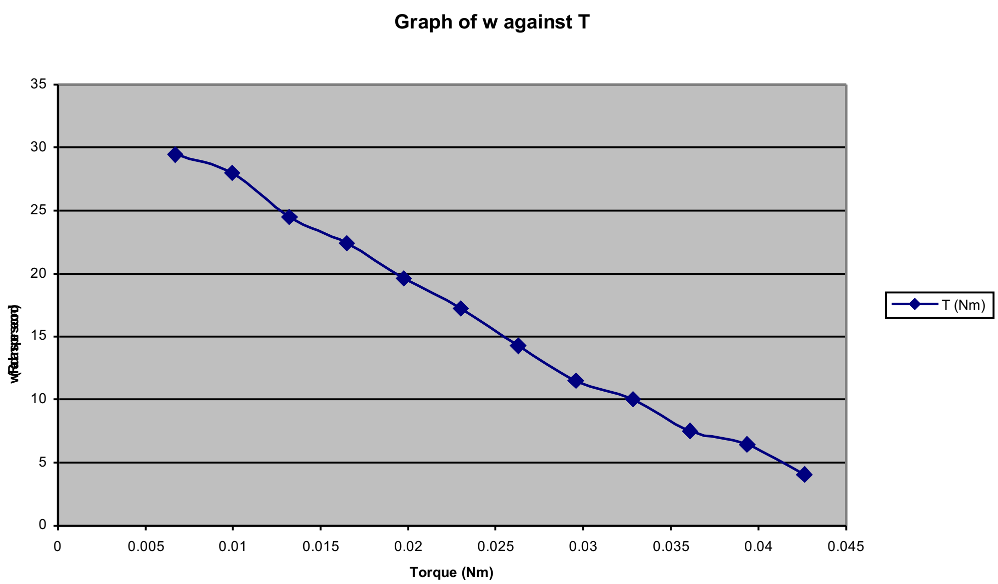
Average Radius=0.02, Force=1/6 of the weight because of the pulley system

⇒T=$\frac{9.8M}{6}$ *0.02

⇒T=$\frac{19.6M}{600}$

Calculating values for T and ω from my results:

Mass (g)	Time taken to lift mass l.025m	ω (Radians per second)	T (Nm)
1304.8	75.72	4.061014263	0.042623467
1204.8	47.84	6.427675585	0.0393568
1104.8	40.97	7.505491823	0.036090133
1004.8	30.69	10.01955034	0.032823467
904.8	26.82	11.46532438	0.0295568
804.8	21.56	14.26252319	0.026290133
704.8	17.84	17.23654709	0.023023467
604.8	15.66	19.63601533	0.0197568
504.8	13.72	22.41253644	0.016490133
404.8	12.57	24.46300716	0.013223467
304.8	11	27.95454545	0.0099568
204.8	10.44	29.45402299	0.006690133



Estimation of y intercept=35

X intercept=0.0465

Calculating the internal resistance of the motor coils:

$R = \frac{V^2}{T\omega}$ (Derived from the equations quoted above) V≈1.3V, T=0.0465, ω=35

⇒R ≈1.0Ω

I made many assumptions when I was calculating R. For example, I assumed that V and R are constant. I also assumed that ω was constant through out my experiment, when it actually decreased as the radius of the motor shaft increased. As a consequence of this the value of the internal resistance is only an estimation.

<u>Can my model predict the amount of energy the motor needs to lift a weight a height of 1.025m?</u>

Predicted Power in using my model= $I^2Rt+\varepsilon It+FD$
Estimation of frictional force≈7N(the force required to just move my pulley system)
R≈1ohm

<u>Using my results to test my model</u>

Mass (g)	**Actual amount of energy used (J)**	**%E**	**Joules lost in motor coils**	**%E**	**Work Done lifting weight**	**%E**	**Work Done against friction**	**% E**	**Predicted amount of Energy used**
Estimated 1g per 100g weight	"=Vit		"=I*I*R*t		"=M*9.8*1.025		"=7*1.025		
Estimated error=1%									
1304.8	155.9832	7.751	302.88	55.396	13.106716	3	7.175	25	323.161716
1204.8	98.93312	7.832	169.085696	55.946	12.102216	3	7.175	25	188.362912
1104.8	84.8079	7.858	132.7428	56.288	11.097716	3	7.175	25	151.015516
1004.8	66.069432	7.968	103.904064	56.412	10.093216	3	7.175	25	121.17228
904.8	53.1036	8.316	73.01745	57.179	9.088716	3	7.175	25	89.281166
804.8	40.1016	8.784	51.7979	57.843	8.084216	3	7.175	25	67.057116
704.8	34.55608	8.883	39.606584	58.393	7.079716	3	7.175	25	53.8613
604.8	29.5974	9.191	30.6936	59.059	6.075216	3	7.175	25	43.943816
504.8	24.9704	9.604	23.1868	59.879	5.070716	3	7.175	25	35.432516
404.8	21.8718	10	18.1008	60.72	4.066216	3	7.175	25	29.342016
304.8	19.2665	10.38	14.0459	61.577	3.061716	3	7.175	25	24.282616
204.8	17.5392	10.76	11.5101	62.397	2.057216	3	7.175	25	20.742316

As you can see my predicted value for the amount of energy used by the motor is about twice the actual amount of energy used. The number of joules lost in the internal resistance is large fraction of the total energy used by the motor. This value has also got a high estimated percentage error and for these reasons I predict that it is the inaccuracy of this value that is causing the difference.

Of the two terms I have used to calculate the energy lost in the internal resistance of the motor, the current and the internal resistance of the motor, the internal resistance is the most uncertain.

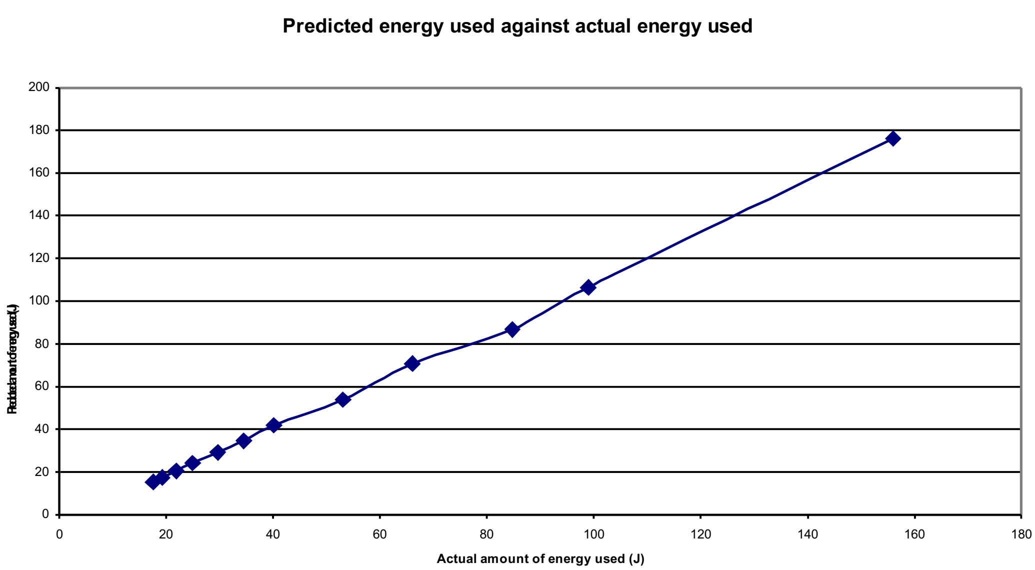
By finding values of the internal resistance and the work done against friction that make the power in = the power predicted I will be able to get better estimations of these values and I will still be able to test my model.

I will try using the internal resistance as 0.51ohms

My results:

Mass (g)	Actual amount to energy used (J)	%E	Joules lost in motor coils	%E	Work Done lifting weight	%E	Work Done against friction	%E	Predicted amount of Energy used
Estimated error=1%									
1304.8	155.9832	7.751	155.9832	55.396	13.106716	3	7.175	25	176.264916
1204.8	98.93312	7.832	87.07913344	55.946	12.102216	3	7.175	25	106.3563494
1104.8	84.8079	7.858	68.362542	56.288	11.097716	3	7.175	25	86.635258
1004.8	66.069432	7.968	53.51059296	56.412	10.093216	3	7.175	25	70.77880896
904.8	53.1036	8.316	37.60398675	57.179	9.088716	3	7.175	25	53.86770275
804.8	40.1016	8.784	26.6759185	57.843	8.084216	3	7.175	25	41.9351345
704.8	34.55608	8.883	20.39739076	58.393	7.079716	3	7.175	25	34.65210676
604.8	29.5974	9.191	15.807204	59.059	6.075216	3	7.175	25	29.05742
504.8	24.9704	9.604	11.941202	59.879	5.070716	3	7.175	25	24.186918
404.8	21.8718	10	9.321912	60.72	4.066216	3	7.175	25	20.563128
304.8	19.2665	10.38	7.2336385	61.577	3.061716	3	7.175	25	17.4703545
204.8	17.5392	10.76	5.9277015	62.397	2.057216	3	7.175	25	15.1599175

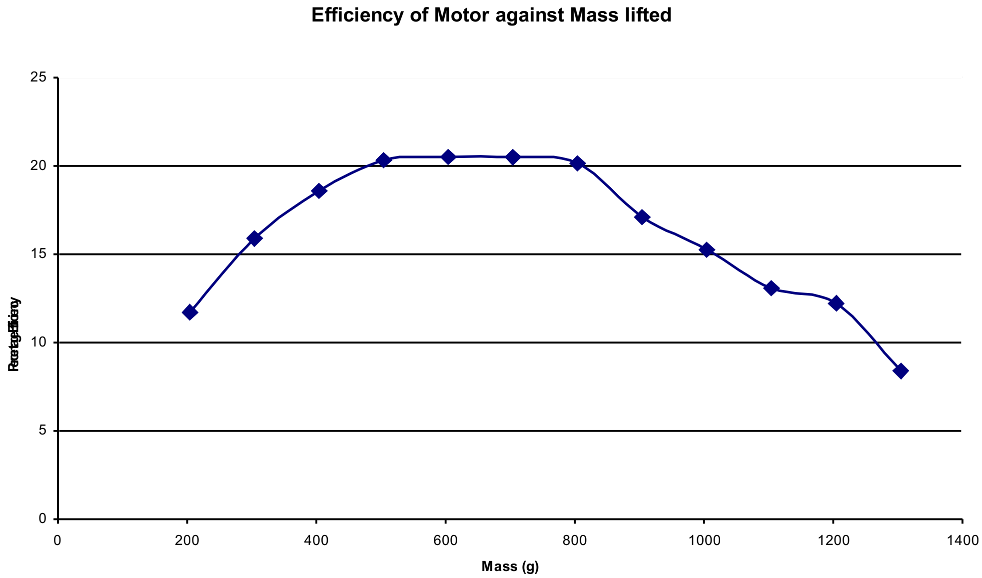
Graph using revised results:



As you can see a value of R=0.51ohms is an accurate estimation of the internal resistance of the motor since it makes the predicted power in very similar to the actual power in. This curve also shows that my model is very accurate since it predicts the energy needed to lift a wide variety of weights. The small curves in the line can be explained by experimental error.

There is still one problem with this curve; this is that it doesn't quite pass through the origin. The graph should theoretically pass through the origin since a motor lifting no weight shouldn't use any power.

Using my model to explain the Efficiency/Weight lifted graph:



My model:
(Energy used by motor)=(Energy lost in the motors internal resistance)+(Work done lifting weight +Work done against friction)
Or $IVt=I^2Rt+\varepsilon It+FD$

For small masses:

When the motor is lifting small masses it does not require much current, since torque of a motor is proportional to the current in the motor coils. This is true since the force exerted on the motor coils is equal to BIL (where B=field strength, L=length of coil perpendicular to the magnetic field, and I=the current). If you look at my results you can see that the current is small for small loads.

When the current is small the work done against friction is the term in which most energy is wasted. This value is very large in comparison to the work done lifting the weight and the energy lost in the motor coils for small currents. As a result of this the motor is not very efficient.

Efficiency for small weights= $\frac{IVt - Fd}{IVt} = 1 - \frac{Fd}{IVt}$

If you assume that the work done against friction is constant, $I \propto M$, and V is constant

$$\Rightarrow E \propto 1 - \frac{k}{Mt}$$

This explains the y=1-1/x form of the first half of the graph..

For large masses:

When lifting heavier weights the motor draws I higher current in order to provide the extra torque required to lift the extra weight. Consequently the I^2Rt component becomes large and the work done against friction becomes insignificant. It follows that the equation can be approximated to:

$IVt=I^2Rt+\varepsilon It$

$$\text{Efficiency} = \frac{IV - I^2R}{IV}$$

$$= 1 - \frac{IR}{V}$$

If we assume that V and R are constant and the and that $I \propto M$, you get a straight line in the form y=mx + c

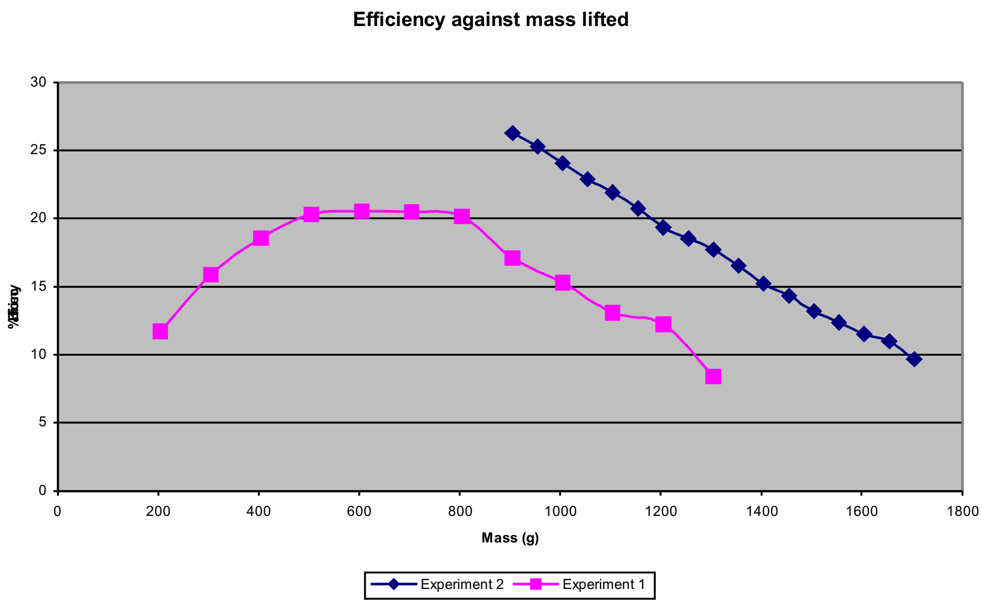
$E \propto 1 - kM$, where $k \propto R/V$

This explains why the later part of my graph appears to be linear.
The percentage efficiency that I got for 1200g weights does not quite fit the pattern of my other results.This was probably caused by experimental error.

<u>Analysis of my results for Experiment 2</u>

In experiment 2 I have tested the efficiency of the motor when lifting masses ranging from 900-1700 grams. Using my results from my last experiment I predict that the efficiency of the motor will decreases linearly with increasing mass.

Weight (g)	Average height lifted with 20J	%E	% Efficiency of motor	%E
Estimated Error=+/- 1%	Estimated Error =+/-0.5cm			1+1+E(h)
904.8	59.25	0.84388	26.268606	2.84388
954.8	54.05	0.92507	25.2874006	2.92507
1004.8	48.9	1.02249	24.0760128	3.02249
1054.8	44.3	1.12867	22.8965436	3.12867
1104.8	40.5	1.23457	21.924756	3.23457
1154.8	36.7	1.3624	20.7667684	3.3624
1204.8	32.8	1.52439	19.3635456	3.52439
1254.8	30.15	1.65837	18.5377878	3.65837
1304.8	27.75	1.8018	17.742018	3.8018
1354.8	24.9	2.00803	16.5299148	4.00803
1404.8	22.1	2.26244	15.2125792	4.26244
1454.8	20.1	2.48756	14.3283252	4.48756
1504.8	17.9	2.7933	13.1986008	4.7933
1554.8	16.25	3.07692	12.380095	5.07692
1604.8	14.65	3.41297	11.5200568	5.41297
1654.8	13.55	3.69004	10.9870446	5.69004
1704.8	11.6	4.31034	9.6900832	6.31034



The efficiency of the motor in experiment 2 does decrease linearly with increasing mass as I predicted.

Ideally the two graphs should follow each other since I used the same motor in each experiment. However from my graph you can see that my calculated efficiency for the second experiment is consistently about 9% higher than the calculated efficiency from my first experiment. This difference has probably been caused by the inaccuracy of the joule meter. This is inconsistent with my results from my calibration experiment. They showed that the joule meter always records more energy that it is receives and therefore if I correct my results for experiment 2 it would make the motor even more efficient.

However the linear sections of the graphs have the same gradient and this shows that in both experiments the efficiency is varying in the same way.

Extension:
Aim: To measuring the efficiency of the electric motor as a generator and to establish if the system is time reversible.
The experiment:
See Diagram for circuit digarm.
Experimental method:
I will dropped a variety of weights a distance of 1.12m and then I recorded the amount of electrical energy produced by the motor using the joule meter

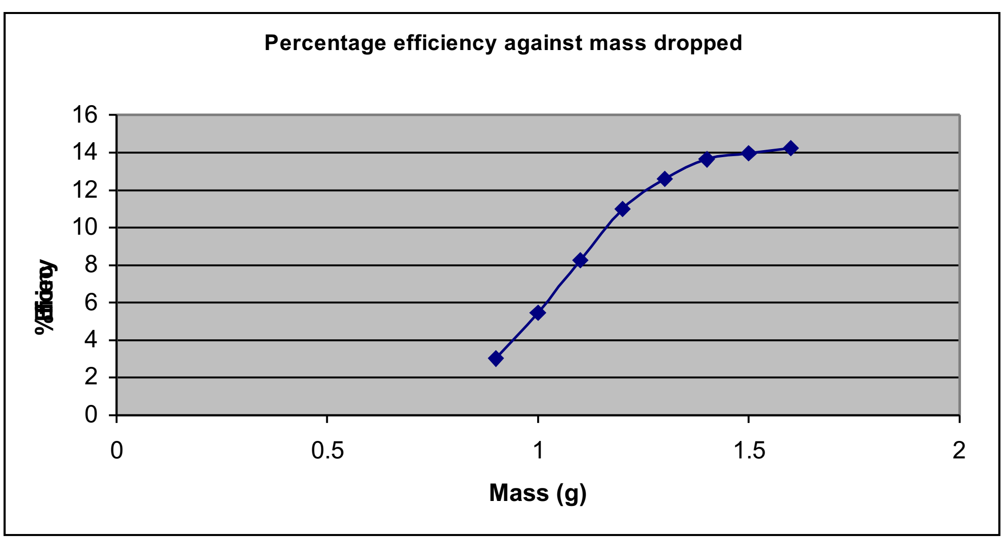
Acknowledged Errors

1. The inaccuracy of the joule meter-however I can use my calibration curve to correct for this
2. Friction in the pulley system
3. The weight has kinetic energy when I hits the ground and this energy is lost from the system thus reducing the efficiency of the generator.

My Results:
H=1.12m load=10.3 ohms

Mass (kg)	Average Time for full drop(s)	Joules recorded Exp1x10	Joules recorded Exp2x10	Average number of joules recordedx10	%E	Energy Input (J)	% Efficiency	%E
Error=1%		Error=+/-1	Error=+/-1	Error=+/-1		Error=3%		
0.7								
0.8								
0.9	21.31	3	3	3	33.3	9.89	3	36.33
1	11.6	6	6	6	16.66	11	5	19.6
1.1	8.9	10	10	10	10	12.1	8	13
1.2	6.5	14	15	14.5	6.896	13.2	11	9.89
1.3	5.4	18	18	18	5.555	14.3	13	8.5
1.4	5	21	21	21	4.761	15.4	14	7.76
1.5	4.7	23	23	23	4.347	16.5	14	7.3
1.6	4.2	25	25	25	4	17.6	14	7

Graph:



Explaining the graph:

The energy I put in the generator is dissipated in three ways.

1. Useful energy is dissipated in the load
2. Energy is lost in the friction of the pulley system
3. When current flows through the internal resistance of the motor energy is lost
4. Energy is lost when the weight I drop hits the flaw

It follows that because energy is conserved:

The Potential energy of the weight=

Power dissipated in load

+ Work done against friction

+Energy Lost in the motor's resistance

+Energy lost as the weight hits the floor

$$Mgh = I^2 R_{load} + Fd + I^2 R_{internal} + \frac{1}{2} MV^2$$

M=mass, I=current, F=friction force, R=resistance, V=final speed of weight

In my analysis I have chosen to ignore the energy lost in the internal resistance of the motor. This is sensible since the energy lost in the internal resistance was insignificant compared to the energy lost in the load. To further simplify things I will also ignore the energy lost as the weight hits the ground. This factor was very small because my weights travelled quite slowly and they had small masses.

Simplified formula for analysis:

$$kM = I^2 R_{load} + FD$$

$$\text{Efficiency} \propto \frac{kM - FD}{kM} \propto 1 - \frac{FD}{kM}$$

If you assume that the work done against friction is constant this formula explains the 1-1/x form of my graph. For small weights the generator is inefficient since most of the weights potential energy is being used to overcome friction. For small the second term of the formula is large and the generator is therefore inefficient. This is shown by my graph.

For large weights the work done against friction becomes insignificant and consequently the generator becomes more increasingly more efficient. For larger the second term would tend to zero and the efficiency should tend to 100%. My results do show that the efficiency increases for heavier weights however my results appear to approach an efficiency of 14% not 100%. This difference may be caused by the fact that for my larger weight the energy lost in the motor's resistance and the energy lost as the weight hit the floor become significant. The inaccuracy of the joule meter may have also contributed to this difference.

Is a the motor time reversible

If my motor was time reversible it should behave in the same way irrespective of the direction of time. For example if you use electrical energy lift a weight with a motor if the system is time reversible you should be able to get the electrical energy back by dropping the weight.

A motor is obviously time reversible to an extent since it can be used both as a motor and a generator. However my results show that for my experiment you are only able to retrieve a small fraction of the energy you used lifting when using the motor as a generator (about 2.5 joules out of 150 or 2%).

This inefficiency can be partially explained by considering the parts of the system that are not time reversible. This includes the friction in the system and the energy lost in the internal resistance of the motor. Here energy is lost as heat and sound that cannot be retrieved.

Conclusion:

In general my experiments went well and I was able to use my result to make some useful conclusions. I was very pleased with the accuracy of my results.

If I had more time I would have taken more experimental reading so that I could get a more complete picture of what was happening. I would also have spent more time calibrating the joule meter since it's inaccuracy had a large effect on my results.

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