# REPORT SUBMISSION FORM

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# DECLARATION OF ORIGINALITY

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| **MECHANICAL EQUIVALENT OF HEAT** |

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| **By** |

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| **TAN WEI LIANG** |

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| --- |
| **February 2024** |

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| **First Year Laboratory Report** |

**MECHANICAL EQUIVALENT OF HEAT**

# ABSTRACT

This study, titled "Alternating Current Resonance," investigates the properties of AC RLC circuits through four key objectives. The resonant frequency of a simple AC RLC series circuit was determined to be (4.50 ±0.01) kHz in the first objective. Moving to the second objective, exploration of the Q factor and resistance revealed a consistent decrease in Q factor with increasing resistance, aligning with theoretical expectations. The third objective examined the phase difference between current and applied voltage in the AC RLC series circuit. The inductor's applied voltage led the source voltage by (1.16±0.01) radians, exhibiting a 71.85% percentage discrepancy. Additionally, the capacitor's applied voltage lagged the source voltage by (1.16±0.01) radians, with a 271.85% percentage discrepancy. In the fourth objective, the resonant frequency of a parallel resonant circuit was determined to be (4.75 ±0.01) kHz. These findings enhance our understanding of AC RLC circuit behavior, offering valuable insights into resonant frequencies, Q factors, resistance effects, and phase relationships.

# ACKNOWLEDGEMENTS

First and foremost, I express my sincere appreciation to *Assoc. Prof. Dr. Lim Hwee San*, our distinguished lecturer and examiner, for the invaluable guidance and unwavering support extended throughout our scientific exploration. I extend special gratitude to *Encik Khairunizam Ahmad* our industrious lab assistant, whose meticulous time management during lab sessions and facilitation of experiment redo processes played a pivotal role in ensuring the seamless execution of our practical work. His assistance has been integral to the success of our hands-on sessions. I extend my sincere gratitude to my redo experiment partner, *Goh Zhia Wue*, and my experiment partner, *Aina Imanina Binti Mohb Khozikin*. Their invaluable cooperation and dedication throughout both experiments were instrumental to the success of this project. I appreciate their commitment, expertise, and teamwork, which made these scientific endeavors both productive and enjoyable. Additionally, I acknowledge the contributions of the original creator of this lab manual, whose identity remains unknown, yet their foundational work stands as a cornerstone to our scientific comprehension. A heartfelt acknowledgment is also extended to *Dr. John Soo Yue Han* for his dedicated efforts in revising and standardizing the manual in 2021, elevating its clarity and educational significance. This collective endeavor has significantly enhanced our scientific learning journey, and I extend genuine gratitude to everyone mentioned for their noteworthy contributions.

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# INTRODUCTION

The purpose of this experiment is to verify the relationship between mechanical energy, or energy associated with motion, and heat, associated with the transfer of energy between objects because of a temperature difference.

# THEORY

The principle of the conservation of energy tells us that if a given amount of work is transformed completely into heat, the resulting thermal energy must be equivalent to the amount of work that was performed. Of course, since work is normally measured in units of Joules and thermal energy is normally measured in units of Calories, the equivalence is not immediately obvious. A quantitative relationship is needed that equates Joules and Calories: This relationship is called the Mechanical Equivalent of Heat.

A well-performed experiment that captures this equivalence is not reasonably achieved. Work is performed by winding the apparatus shown in Figure 1. A measurable amount of work is performed by turning the crank, which turns the aluminum cylinder. A nylon rope is wrapped several times around the cylinder so that, as the crank is turned, the friction between the rope and the cylinder is just enough to support a mass hanging from the other end of the rope. This insures that the torque acting on the cylinder is constant and measurable. A counter keeps track of the number of turns.

As the cylinder turns, the friction between the cylinder and the rope converts the work into thermal energy, which raises the temperature of the aluminum cylinder. A thermistor is embedded in the aluminum so that, by measuring the resistance of the thermistor, the temperature of the cylinder can be determined. By monitoring the temperature change of the cylinder, the thermal energy transferred into the cylinder can be calculated. Finally, the ratio between the work performed and the thermal energy transferred into the cylinder determines J, the mechanical equivalent of heat.

**Measuring Temperature with the Thermistor**

To measure the temperature of the aluminum cylinder, a thermistor is embedded inside. A thermistor is a temperature dependent resistor. If the resistance of the thermistor is known, its temperature can be very accurately and reliably determined. The leads of the thermistor in the cylinder are soldered to the copper slip rings on the side of the cylinder. The brushes providing an electrical connection between the slip rings and the banana plug connectors. By plugging an ohmmeter into these connectors, the resistance of the thermistor, and therefore its temperature, can be monitored, even when the cylinder is turning.

Although the temperature dependence of the thermistor is accurate and reliable, it is not linear. You will therefore need to use the table of Temperature versus Resistance given at the end of this manual to convert your resistance measurements into temperature readings.

# EXPERIMENTAL METHODOLOGY

**Part A**

**Important Instructions**

Below are two experiments to obtain the mechanical heat equivalent. Do experiment A in the first week and experiment B in the second week. After the end of each experiment, complete the worksheets provided and submit them for assessment. Only submit worksheet A for experiment A and worksheet B for experiment B. Do not collect your worksheet A when doing experiment B. If you do, you will not obtain any marks for experiment A.

**EXPERIMENTAL PROCEDURE**

The method used in this experiment in finding the mechanical heat equivalent J, is by frictional method between a string placed around an aluminum cylinder making at least 4 to 6 turns where one end of the string is tied to the holder and the other end tied to a weight left hanging above the floor (refer to Figure 1). The string tied to the holder, and weight is strained at the beginning of the experiment. When the handle is turned steadily, the weight will then be less strained and 'stay fixed at a particular point. This happens when all the forces acting on the system is in equilibrium. If the cylinder is rotated steadily at equilibrium, work by the frictional force of the string on the cylinder is equivalent to the work by the weight on the string.

**A. Symmetrical Room Temperature Experiment**

**1：Method**

a. Measure the resistance of the aluminum cylinder using a digital multimeter in kΩ and then, the corresponding temperature is obtained by the interpolation of data from the table of Resistance versus Temperature given at the back of the manual for its equivalent in °C. Then, take off the aluminum cylinder from the holder of the experimental setup and weigh it (in grams, g). Also measure its diameter.

b. Cool the cylinder in iced water (water mixed with some ice) until its temperature reaches at least 10°C below room temperature (around 10 mins). Then, dry the cylinder (dab dry) and place the cylinder back to its holder quickly. Make sure that the cylinder is inserted into the holder correctly so that the notch on the cylinder fits exactly into the pin of the holder. This is to ensure good electrical contact.

c. Place a string around the cylinder making at least 4 to 6 turns. Be sure that the string lies flat against the cylinder and hangs down. Then, place a weight of between 1.5 to 2 kg on the other end of the string around 3 cm from the floor. This must be done rather quickly to ensure that the temperature of the cylinder has not increased significantly in the process of fitting the cylinder into the holder and getting the experiment set up.

d. Then, measure the resistance again using the digital multimeter and set the counter at '0'. Crank the handle of the cylinder steadily until the corresponding temperature reaches a few °C higher than room temperature. Using the table of Resistance versus Temperature for the thermistor, determine the temperature values which correspond to each of your recorded resistance value. After the experiment is over, take down the number of turns, N, on the counter.

2. Calculating the Mechanical Heat Equivalent:

Calculating W, the Work Performed

The work performed on the cylinder by turning the crank equals τθ, the torque acting on the cylinder, times θ, the total angle through which the torque acts. It would be difficult to directly measure the torque delivered by the crank. However, since the motion of the cylinder is more or less constant through the experiment, we know that the torque provided by the crank must just balance the torque provided by the friction from the rope. The torque provided by the rope friction is easily calculated. It is just:

τ = MgR (1)

Each time the crank is turned one full turn, this torque is applied to the cylinder through an angle 2π. The total work performed therefore is:

W' = τθ = MgR (2πN) (2)

W = MgR/2 (2πN) = mtgDN/2 (where N is the number of turns of the cylinder, R [m] is the radius of the cylinder, D [m] is the diameter of the cylinder, M [Kg] is the weight hanging at the end of the string and g is the gravitational acceleration.)

Calculating Q, the Heat produced

The heat (Q) produced by friction against the aluminum cylinder can be determined from the measured temperature change that occurred. The calculation is:

Q = mC (Tf - Ti) (4)

where m [g] is the mass of the cylinder, Tf is the final temperature and Ti is the initial temperature of the cylinder.

Calculating J, the Mechanical Equivalent of Heat

The mechanical heat equivalent is just the ratio of the work performed to the heat produced and calculated by the following equation;

J = W/Q = mtgDN/2 / mC(Tf - Ti) (5)

(Assume that the gravitational acceleration is g = 9.8 m/s² and the specific heat capacity of aluminum is C = 0.220 cal/g°C.)

**B. Non-Symmetrical Room Temperature Experiment**

**1. Method**

a. For this experiment, the experimental setup is similar to experiment A except that the aluminum cylinder is not cooled. Instead, the aluminum cylinder is initially at room temperature, �0*T*0​. Take down this temperature, set a stop clock to ‘0’ and begin turning the handle of the holder steadily until its temperature increases and reaches ��*Ta*​, the final temperature of the cylinder. Take temperature increases and increased every 20-30 seconds. Don’t forget to set the counter to ‘0’ before you begin and take down the number of turns, �*N* at the end of the experiment. The temperature range between ��*Ta*​ and �0*T*0​ must be at least 10°C or just a little higher. This is the heating part of the experiment. Enter your data into the table given in worksheet B.

b. After the final temperature ��*Ta*​ is reached, stop turning the cylinder and allow it to cool down naturally until it returns to almost room temperature. Continue taking the temperature decreased every 30 seconds to 1 minute. This is the cooling part of the experiment. Enter your data into the table given in worksheet B. Then plot a heating and cooling graph for aluminum from the data you have obtained. Refer to Figure 2 for reference.

c. As the surrounding temperature is lower than the temperature of the cylinder ��*Ta*​, some of the heat will be dissipated. If this dissipated heat is taken into account, the true final temperature should have been higher than ��*Ta*​. According to Newton’s second law, the characteristics of cooling characterized by a rate of its time, �*T* is the cooling law, the rate of cooling ����*dtdT*​ for a system related to its surroundings is proportional to the difference between the temperature of the system, �*T* and its surroundings, �0*T*0​ as given below;

����=−�(�−�0)*dtdT*​=−*K*(*T*−*T*0​) (6)

where �*K* is the cooling constant for the system.

The value of �*K* can be obtained from the heating and cooling curve. The data is obtained from the increase in temperature of the aluminum cylinder in the experiment to ��*Ta*​ during the heating process and the decrease in temperature to room temperature �0*T*0​ during the cooling process.

Solving equation (6), we will obtain the following;

ln⁡(�−�0��−�0)=−�(�−��)ln(*Ta*​−*T*0​*T*−*T*0​​)=−*K*(*t*−*ta*​) (7)

By plotting the graph of ln⁡(�−�0��−�0)ln(*Ta*​−*T*0​*T*−*T*0​​) versus (�−��)(*t*−*ta*​), which is a straight-line curve, −�−*K* is the gradient of the curve and can be easily found.

d. Plot the graph of ln⁡(�−�0��−�0)ln(*Ta*​−*T*0​*T*−*T*0​​) versus (�−��)(*t*−*ta*​) and find �*K*.

**Figure 2. Heating and cooling graph for aluminum.**

The figure shows the heating curve, the final temperature ��*Ta*​, the corrected final temperature, the corrected heating curve, the cooling curve, room temperature �0*T*0​, and the time �*t* on the x-axis, with ��*ta*​ marked where the final temperature is reached.

In order to calculate the temperature correction due to heat dissipated to the surroundings, according to equation (6), the change in temperature for each time interval Δ�Δ*t* is ∣Δ�∣=�(�−�0)Δ�∣Δ*T*∣=*K*(*T*−*T*0​)Δ*t*. During the process of heating, from time �=0*t*=0 to ��*ta*​ for �*n* intervals of Δ�Δ*t*, we will obtain ��=�Δ�*ta*​=*n*Δ*t* so that the subsequent changes in temperature �1,�2,...,��*T*1​,*T*2​,...,*Tn*​ proceed as the following:

Δ�1=�(�1−�0)Δ�Δ*T*1​=*K*(*T*1​−*T*0​)Δ*t*

which is the temperature correction for temperature �1*T*1​. The correction Δ�2Δ*T*2​ for temperature �2*T*2​ is

Δ�2=�(�2−�0)Δ�+Δ�1=�(�1+�2−2�0)Δ�Δ*T*2​=*K*(*T*2​−*T*0​)Δ*t*+Δ*T*1​=*K*(*T*1​+*T*2​−2*T*0​)Δ*t* and so on

Eventually, we will obtain the �*n*th correction as follows;

Δ��=�(�1+�2+...+��−��0)Δ�Δ*Tn*​=*K*(*T*1​+*T*2​+...+*Tn*​−*nT*0​)Δ*t*

The expression above is only for the heating process. If the number of time intervals �*n* is considered for the whole process including the cooling process, the above expression need to be multiplied by a factor of 1221​ so that the real temperature correction for ��*Ta*​ is as follows

ΔTₐ = ½ K(T₁ + T₂ + ... + Tₙ - nT₀)Δt (8)

If n is large enough, the change in temperature for each subsequent time interval will be small and assumed to be the same so that equation (8) above is approximated as below;

ΔTₐ = ½ K(Tₐ - T₀)Δt (9)

Equation (9) is used for large n which include the heating and cooling processes (the number of time intervals from 0 to tₐ for heating and from tₐ to tₙ for cooling). Here, ΔTₐ = 0 during heating. However, if n is small, then equation (8) is used. Then, the true corrected temperature is calculated as follows;

Tₘ = Tₐ + ΔTₐ (10)

1. Calculating the Mechanical Heat Equivalent

The calculation of work for the system is the same as in experiment A.

However, the heat absorbed by the cylinder is

Q = mC(Tₘ - Tᵢ) (11)

The mechanical equivalent of heat is calculated using the ratio, J = W / Q

If the experiments are conducted carefully, the expected uncertainty is well within 5%.

*Prepared by Assoc. Prof. Fauziah Sulaiman (June 2009)*

# DATA ANALYSYS

**Part A**

Mass of weight at the end of the string, M = kg

Mass of aluminium cylinder, m = g

Diameter of aluminium cylinder, D = m

Number of rotations (turns) of the aluminium cylinder, N = 648

|  |  |  |
| --- | --- | --- |
|  | Temperature (℃) | Equivalent Resistance (kΩ) |
| Room Temperature |  |  |
| Initial temperature of aluminium cylinder, Ti |  |  |
| Final temperature of aluminium cylinder, Tf |  |  |

Calculation of J

Specific heat capacity of cylinder

*H* = *mC*

= (0.220)

= cal/℃

* Work done by frictional force

*Ws* = π*MgDN*

*=* π () (9.8) () () = J

Heat absorbed by the cylinder

*Q* = *mC* (*Ti* -*Tf* )

= (0.220) ( - )

= cal

* Mechanical heat equivalent

*Js* =

=

= J/cal

Error Calculation of Js

Percentagediscrepancy =

=

= %

Experiment B

Number of rotations(turns) of cylinder during heating, *N* = turns

**TABLE OF INCREASING TEMPERATURE**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Time  (second) | Equivalent resistance (kΩ) | Temperature (℃) | Time  (second) | Equivalent Resistance (kΩ) | Temperature  (℃) |
| 0 |  |  | 420 |  |  |
| 30 |  |  | 450 |  |  |
| 60 |  |  | 480 |  |  |
| 90 |  |  | 510 |  |  |
| 120 |  |  | 540 |  |  |
| 150 |  |  | 570 |  |  |
| 180 |  |  | 600 |  |  |
| 210 |  |  | 630 |  |  |
| 240 |  |  | 660 |  |  |
| 270 |  |  | 690 |  |  |
| 300 |  |  | 720 |  |  |
| 330 |  |  | 750 |  |  |
| 360 |  |  | 780 |  |  |
| 390 |  |  | 810 |  |  |

T0 (Room Temperature) = ℃

Ta (Final Temperature) = ℃

**TABLE OF DECREASING TEMPERATURE**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Time  (second) | Equivalent resistance (kΩ) | Temperature (℃) | Time  (second) | Equivalent Resistance  (kΩ) | Temperature  (℃) |
| 0 |  |  | 870 |  |  |
| 30 |  |  | 900 |  |  |
| 60 |  |  | 930 |  |  |
| 90 |  |  | 960 |  |  |
| 120 |  |  | 990 |  |  |
| 150 |  |  | 1020 |  |  |
| 180 |  |  | 1050 |  |  |
| 210 |  |  | 1080 |  |  |
| 240 |  |  | 1110 |  |  |
| 270 |  |  | 1140 |  |  |
| 300 |  |  | 1170 |  |  |
| 330 |  |  | 1200 |  |  |
| 360 |  |  | 1230 |  |  |
| 390 |  |  | 1260 |  |  |
| 420 |  |  | 1290 |  |  |
| 450 |  |  | 1320 |  |  |
| 480 |  |  | 1350 |  |  |
| 510 |  |  | 1380 |  |  |
| 540 |  |  | 1410 |  |  |
| 570 |  |  | 1440 |  |  |
| 600 |  |  | 1470 |  |  |
| 630 |  |  | 1500 |  |  |
| 660 |  |  | 1530 |  |  |
| 690 |  |  | 1560 |  |  |
| 720 |  |  | 1590 |  |  |
| 750 |  |  | 1620 |  |  |
| 780 |  |  | 1650 |  |  |
| 810 |  |  | 1680 |  |  |
| 840 |  |  | 1710 |  |  |
| 1740 |  |  | 2700 |  |  |
| 1770 |  |  | 2730 |  |  |
| 1800 |  |  | 2760 |  |  |
| 1830 |  |  | 2790 |  |  |
| 1860 |  |  | 2820 |  |  |
| 1890 |  |  | 2850 |  |  |
| 1920 |  |  | 2880 |  |  |
| 1950 |  |  | 2910 |  |  |
| 1980 |  |  | 2940 |  |  |
| 2010 |  |  | 2970 |  |  |
| 2040 |  |  | 3000 |  |  |
| 2070 |  |  | 3030 |  |  |
| 2100 |  |  | 3060 |  |  |
| 2130 |  |  | 3090 |  |  |
| 2160 |  |  | 3120 |  |  |
| 2190 |  |  | 3150 |  |  |
| 2220 |  |  | 3180 |  |  |
| 2250 |  |  | 3210 |  |  |
| 2280 |  |  | 3240 |  |  |
| 2310 |  |  | 3270 |  |  |
| 2340 |  |  | 3300 |  |  |
| 2370 |  |  | 3330 |  |  |
| 2400 |  |  | 3360 |  |  |
| 2430 |  |  | 3390 |  |  |
| 2460 |  |  | 3420 |  |  |
| 2490 |  |  | 3450 |  |  |
| 2520 |  |  | 3480 |  |  |
| 2550 |  |  | 3510 |  |  |
| 2580 |  |  | 3540 |  |  |
| 2610 |  |  | 3570 |  |  |
| 2640 |  |  | 3600 |  |  |
| 2670 |  |  | 3630 |  |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 3660 |  |  | 4170 |  |  |
| 3690 |  |  | 4200 |  |  |
| 3720 |  |  | 4230 |  |  |
| 3750 |  |  | 4260 |  |  |
| 3780 |  |  | 4290 |  |  |
| 3810 |  |  | 4320 |  |  |
| 3840 |  |  | 4350 |  |  |
| 3870 |  |  | 4380 |  |  |
| 3900 |  |  | 4410 |  |  |
| 3930 |  |  | 4440 |  |  |
| 3960 |  |  | 4470 |  |  |
| 3990 |  |  | 4500 |  |  |
| 4020 |  |  | 4530 |  |  |
| 4050 |  |  | 4560 |  |  |
| 4080 |  |  | 4590 |  |  |
| 4110 |  |  | 4620 |  |  |
| 4140 |  |  | 4650 |  |  |

**Graph of Temperature against Time**

T0 (Room Temperature) = ℃

Ta (Final Temperature) = ℃

ta = s

|  |  |  |  |
| --- | --- | --- | --- |
| T (℃) | t (s) | ln | *(t – ta)* |
|  | 300 |  |  |
|  | 600 |  |  |
|  | 900 |  |  |
|  | 1200 |  |  |
|  | 1500 |  |  |
|  | 1800 |  |  |
|  | 2100 |  |  |
|  | 2400 |  |  |
|  | 2700 |  |  |
|  | 3000 |  |  |
|  | 3300 |  |  |

Calculation of J

From the graph of ln versus *(t – ta)*, explain how you obtained the K constant.

K= gradient of the graph of ln versus *(t – ta)*

Calculation of the true corrected final temperature

∆*Ta =*

= () ( – ) (300) = ℃

*Tm* =*Ta* + ∆*Ta* = + = ℃

Work done due to friction

*WT* =*πMgDN* =*π* () (9.8) () () = J

Heat absorbed by the cylinder

*QT* = *mC* (*Tm* -*T0*) = ( - ) = cal

Mechanical heat equivalent

*JT = = =*  J/cal

Error calculation of *JT*

Percentagediscrepancy =

=

= %

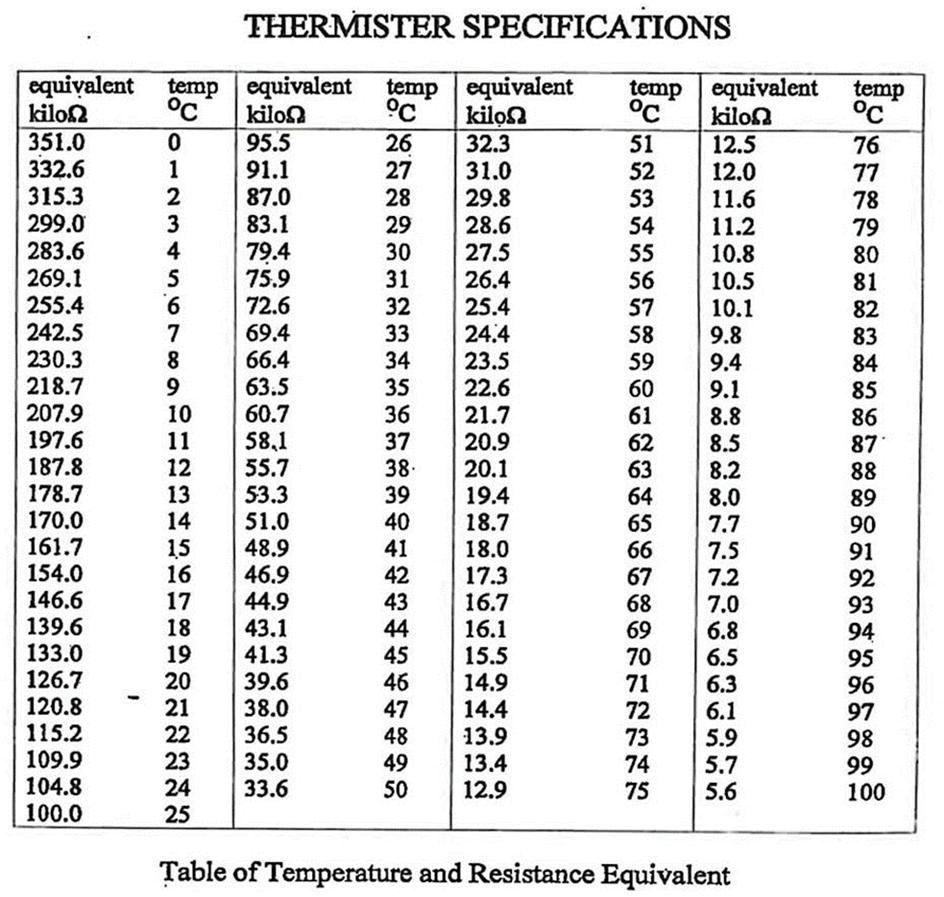
# DISCUSSION AND CONCLUSION

**DISCUSSION**

**CONCLUSION**

# REFERENCES

# APPENDICES



QUESTIONS FROM WORKSHEET A:

1. Is it better to crank the aluminium cylinder rapidly? Why and why not?

Rapidly cranking an aluminum cylinder minimizes environmental heat loss, which is advantageous for maintaining experimental control. However, it's crucial to acknowledge that increased crank speed can lead to elevated frictional heat generation. This additional heat source might interfere with accurate measurements in studies focusing on specific heat or thermal conductivity. Consequently, the crank speed should be carefully calibrated to achieve a balance between reducing heat loss to the environment and mitigating the generation of excess frictional heat.

2. Is it experimentally possible that the heat absorbed by the cylinder could be greater than the work performed on it? Explain.

It is impossible. According to the principle of energy conservation, the scenario where the heat absorbed by a cylinder surpasses the work done on it is theoretically implausible. Energy cannot be generated or destroyed in isolation. Nevertheless, practical experiments often exhibit variances due to factors such as environmental heat losses, systemic inefficiencies, and inaccuracies in measurement. While an ideal, perfectly isolated system would exhibit a direct correlation between work input and heat output, real-world experiments frequently deviate from this ideal due to external factors.

3. Can your value of J be used for determining how much mechanical energy can be produced from a specified amount of thermal energy? Why or why not?

Can not. The mechanical equivalent of heat (J) provides a theoretical basis for converting mechanical work into heat. This conversion factor is pivotal for understanding the interrelation between mechanical and thermal energy. However, J primarily serves as a theoretical guide rather than a definitive tool for practical energy conversion scenarios. Real-world applications necessitate consideration of additional variables such as the efficiency of the system, energy losses during the conversion process, and the specific characteristics of the energy conversion mechanism. While J offers fundamental insights, the actual conversion of energy in practical settings involves a multitude of factors, making direct or one-to-one conversions relatively uncommon.

1