WORKSHEET A

ZCA 191/2 and ZCA 192/2: LABORATORY PHYSICS 100

MECHANICAL HEAT EQUIVALENT

PLEASE SUBMIT WORKSHEET A ONLY AT THE END OF THE FIRST WEEK EXPERIMENT

Name: TAN WEI LIANG
Group: M5B
Date of experiment: 22/1/2024
Lab partner's name: AINA IMANINA BINTI MOHB KHOZIKIN

Objective

To investigate the value of the mechanical heat equivalent by friction method (Symmetrical Room Temperature Experiment)

Data

Mass of weight at the end of the string, $M = 2.0$ kg
Mass of aluminum cylinder, $m = 202.4 \pm 0.1$ g
Diameter of aluminum cylinder, $D = 0.04765 \pm 0.00005$ m
Number of rotations (turns) of the aluminum cylinder, $N = 807$

Temperature and Equivalent Resistance

	Temperature [$°C$]	**Equivalent Resistance [kΩ]**
Room temperature	30	80.0
Initial temperature of aluminum cylinder, T_i	20	126.7
Final temperature of aluminum cylinder, T_f	33	69.4

Calculation of J_s

Specific heat capacity of cylinder

$$H = mc = (202.4)(0.220) = 44.528\, cal/^oC$$

Work done by frictional forces

$$W_s = \pi MgDN = \pi(2.0)(9.8)(0.04765)(807) = 2368\, J$$

Heat absorbed by the cylinder

$$Q = H(T_f - T_i) = (44.528)(33 - 20) = 578.864\, cal$$

Mechanical heat equivalent

$$J_s = \frac{W_s}{Q} = \frac{2368}{578.864} = 4.091\, J/cal$$

Error calculation of J

$$\begin{aligned} J_s =& \frac{W_s}{Q} = \frac{\pi MgDN}{mc(T_f - T_i)} \\ \Delta J_s =& J_s\sqrt{(\frac{\Delta D}{D})^2 + (\frac{\Delta m}{m})^2} \\ =& 4.091\sqrt{(\frac{0.00005}{0.04765})^2 + (\frac{0.1}{202.4})^2} \\ =& 0.005 J/cal \end{aligned}$$

$$\begin{aligned} percentage\, discrepancy =& \frac{|J_s - J_o|}{J_o} \times 100\% \\ =& \frac{|4.091 - 4.184|}{4.184} \times 100\% \\ =& 2.22\% \end{aligned}$$

Therefore, the mechanical heat equivalent including error is

$$J_s = (4.091 \pm 0.005)\, J/cal$$

Answer the Following Questions

1. Is it better to crank the aluminum 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.

WORKSHEET B

ZCA 191/2 and ZCA 192/2: LABORATORY PHYSICS 100
MECHANICAL HEAT EQUIVALENT

PLEASE SUBMIT WORKSHEET B ONLY AT THE END OF THE SECOND WEEK EXPERIMENT

Name: TAN WEI LIANG
Group: M5B
Date of experiment: 22/1/2024
Lab partner's name: AINA IMANINA BINTI MOHB KHOZIKIN

Objective

To investigate the value of the mechanical heat equivalent by friction method (Non-Symmetrical Room Temperature Experiment)

Data

Number of rotations (turns) of cylinder during heating, $N = 754$

TABLE OF INCREASING TEMPERATURE

time, s	**equivalent resistance, kΩ**	**temperature, ^{o}C**
0	81.0	29.6
30	79.3	30.0
60	77.1	30.7
90	74.6	31.4
120	72.2	32.1
150	70.0	32.8
180	67.8	33.5
210	65.7	34.2
240	63.4	35.0
270	62.4	35.4
300	60.3	36.1
330	58.3	36.9
360	58.0	37.0
390	56.8	37.5
420	56.0	37.9
450	54.6	38.5
480	53.4	39.0
510	52.6	39.3
540	51.2	39.9

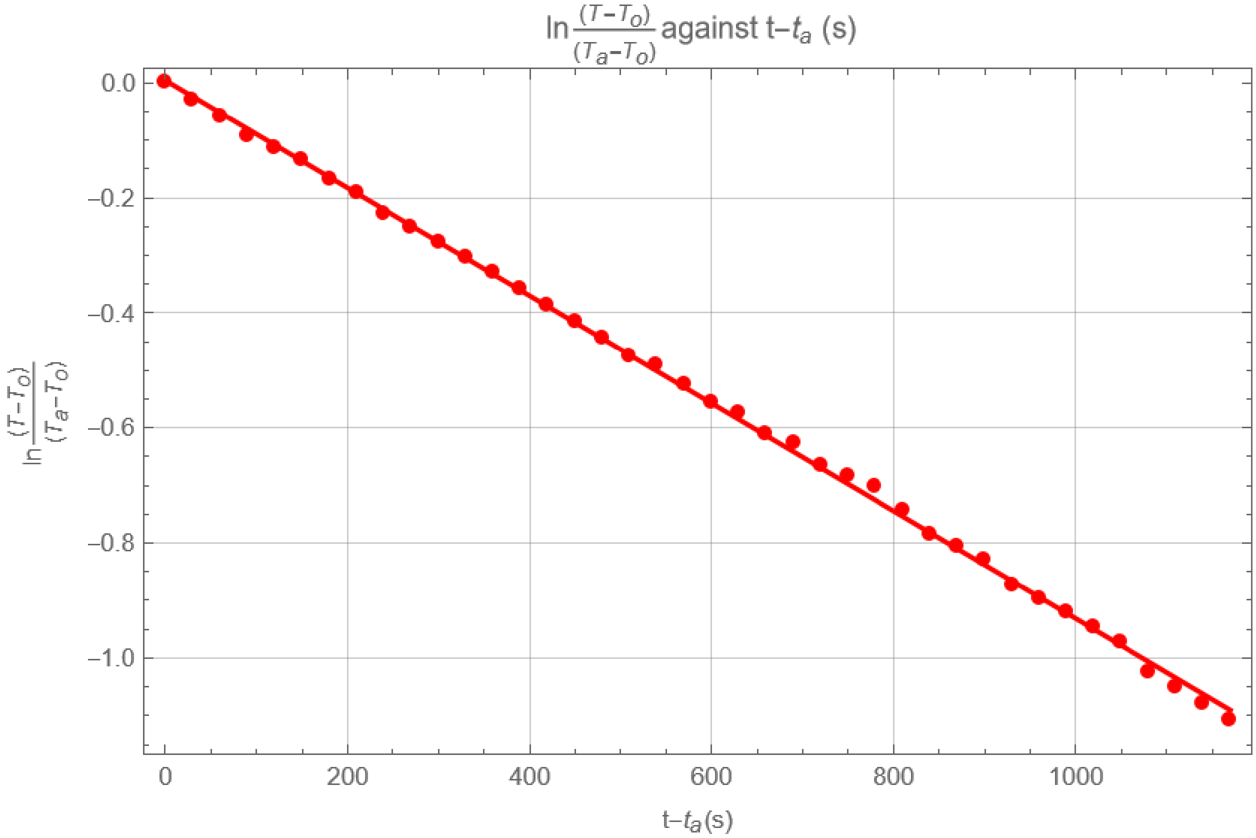
TABLE OF DECREASING TEMPERATURE

time, s	equivalent resistance, kΩ	temperature, ^oC
0	51.2	39.9
30	51.9	39.6
60	52.6	39.3
90	53.2	39.0
120	53.8	38.8
150	54.3	38.6
180	54.9	38.3
210	55.5	38.1
240	56.1	37.8
270	56.6	37.6
300	57.2	37.4
330	57.7	37.2
360	58.2	37.0
390	58.6	36.8
420	59.1	36.6
450	59.6	36.4
480	60.1	36.2
510	60.6	36.0
540	61.0	35.9
570	61.5	35.7
600	62.0	35.5
630	62.5	35.4
660	62.8	35.2
690	63.3	35.1
720	63.7	34.9
750	64.1	34.8
780	64.5	34.7
810	64.9	34.5
840	65.4	34.3
870	65.8	34.2
900	66.2	34.1
930	66.6	33.9
960	66.9	33.8
990	67.3	33.7
1020	67.6	33.6
1050	68.0	33.5
1080	68.4	33.3
1110	68.8	33.2
1140	69.2	33.1
1170	69.5	33.0

TABLE OF DATA FOR GRAPHING

time, s	**temperature, ^{o}C**	t - t_a (s)	$\ln \frac{T-T_o}{T_a-T_o}$
570	39.9	0	0.000
600	39.6	30	-0.030
630	39.3	60	-0.060
660	39.0	90	-0.091
690	38.8	120	-0.113
720	38.6	150	-0.135
750	38.3	180	-0.169
780	38.1	210	-0.192
810	37.8	240	-0.228
840	37.6	270	-0.253
870	37.4	300	-0.278
900	37.2	330	-0.304
930	37.0	360	-0.331
960	36.8	390	-0.358
990	36.6	420	-0.386
1020	36.4	450	-0.415
1050	36.2	480	-0.445
1080	36.0	510	-0.476
1110	35.9	540	-0.492
1140	35.7	570	-0.524
1170	35.5	600	-0.557
1200	35.4	630	-0.574
1230	35.2	660	-0.609
1260	35.1	690	-0.627
1290	34.9	720	-0.664
1320	34.8	750	-0.683
1350	34.7	780	-0.703
1380	34.5	810	-0.743
1410	34.3	840	-0.785
1440	34.2	870	-0.806
1470	34.1	900	-0.828
1500	33.9	930	-0.874
1530	33.8	960	-0.897
1560	33.7	990	-0.921
1590	33.6	1020	-0.946
1620	33.5	1050	-0.971
1650	33.3	1080	-1.024
1680	33.2	1110	-1.051
1710	33.1	1140	-1.079
1740	33.0	1170	-1.108

Graph of $\ln\left(\frac{T-T_0}{T_a-T_0}\right)$ **versus** $(t-t_a)$



`Linear equation:` $y = 0.00390156 - 0.000935358\,x$

`, Uncertainty in Slope:` 4.15843×10^{-6}

Figure 1: Graph of $\ln\left(\frac{T-T_0}{T_a-T_0}\right)$ versus $(t-t_a)$

Gradient is taken and generated by using Mathematica programing

Graph of temperature, T versus time, t

Show the corrected temperature in the graph

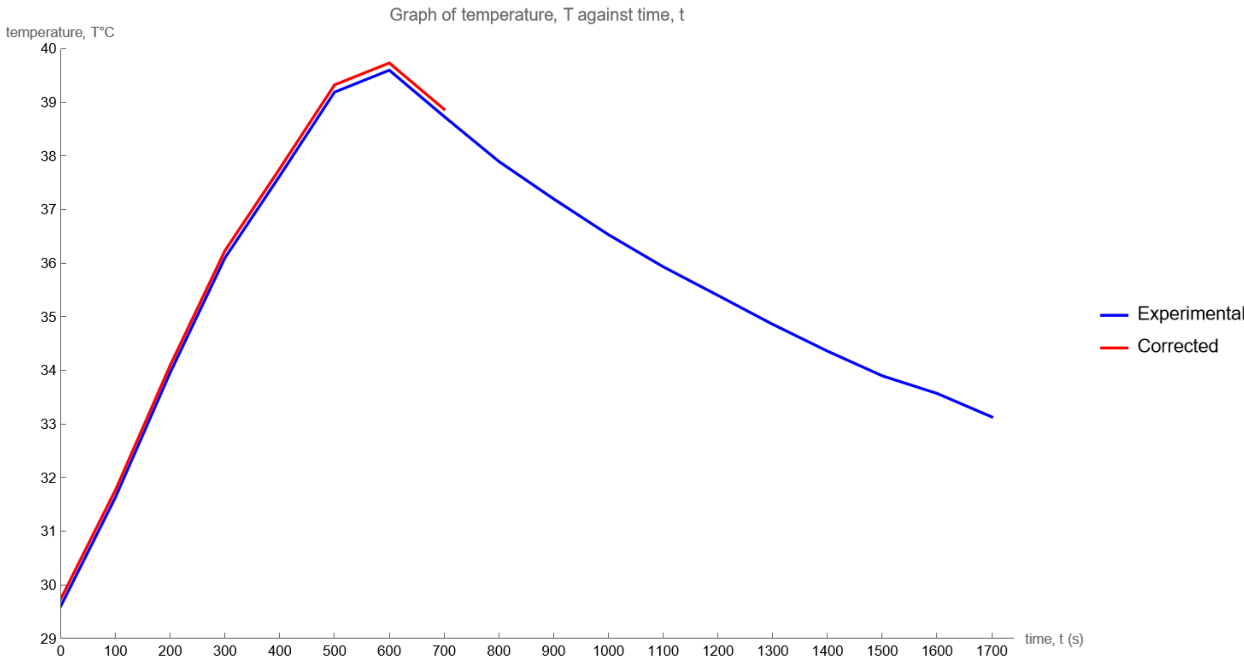


Figure 2: Graph of temperature, T versus time, t

Based on the graph
T_o =29.6
T_a = 39.6

CALCULATION OF J

From the graph of $\ln\left(\frac{T-T_0}{T_a-T_0}\right)$ versus $(t-t_a)$, explain how you obtained the K constant.
$K = gradient\, of\, the\, graph\, of\, temperature,\, T\, versus\, time,\, t$
$K = 0.009\, s^{-1}$

Calculation of the corrected temperature

$$\begin{aligned}\Delta T_a =& \frac{1}{2}k(T_a - T_o)(\Delta t)\\ &= \frac{1}{2}0.0009(39.6 - 29.6)(30)\\ &= 0.135\,^oC\end{aligned}$$

$$\begin{aligned}T_m &= T_a + \Delta T_a\\ &= 39.6 + 0.135\\ &= 39.7\,^oC\end{aligned}$$

Work done due to friction

$$\begin{aligned}W_T &= \pi MgDN\\ &= \pi(2.0)(9.8)(0.04765)(754)\\ &= 2212\,J\end{aligned}$$

Heat absorbed by the cylinder

$$\begin{aligned}Q =& H(T_m - T_0)\\ =&(44.528)(39.7 - 29.6)\\ =&449.7328\,cal\end{aligned}$$

Therefore, the mechanical heat equivalent is

$$J_T = \frac{W_T}{Q} = \frac{2212}{449.7328} = 4.918\,J/cal$$

Error calculation of J_T

$$
\begin{aligned}
J_T =& \frac{W_T}{Q} = \frac{\pi M g D N}{mc(T_m - T_0)} \\
\Delta J_T =& J_T \sqrt{(\frac{\Delta D}{D})^2 + (\frac{\Delta m}{m})^2} \\
=& 4.918 \sqrt{(\frac{0.00005}{0.04765})^2 + (\frac{0.1}{202.4})^2} \\
=& 0.006 J/cal
\end{aligned}
$$

$$
\begin{aligned}
percentage\, discrepancy =& \frac{|J_s - J_o|}{J_o} \times 100\% \\
=& \frac{|4.918 - 4.184|}{4.184} \times 100\% \\
=& 17.54\%
\end{aligned}
$$

Therefore, the mechanical heat equivalent including error is

$$J_T = (4.918 \pm 0.006)\, J/cal$$

Discussion and Conclusion

Discussion

In part A, we observed notable discrepancies in the values of the mechanical equivalent of heat (J). The experimentally determined value of J was found to be 4.091 J/cal, which deviates by 2.22% from the theoretical value of 4.184 J/cal. This significant variance can be attributed to a range of systematic and random Errors in the Experiment.

Firstly, systematicl errors such as Inaccuracies in instruments like multimeter, scales, or timers can introduce consistent errors. Calibrating these instruments or using more precise ones can reduce such errors.Experimental setup also must be carefully, If the setup has inherent flaws, like friction in a pulley system or heat loss to the environment, these can cause systematic deviations. If these losses are not appropriately accounted for in our calculations, they can substantially skew the accuracy of our results. Improving insulation and minimizing friction are ways to address this.

Additionally, Random error such as environmental variations with fluctuations in room temperature, humidity, or air currents can introduce random errors. Conducting experiments in a controlled environment can mitigate these factors. Human error such as short reaction time to the change of results which is difficult to the human's eye to capture the change of the timer or readings of multimeter. Repeated measurements and averaging results can reduce the impact of these errors. Another is Variations in material properties, like slight differences in the composition of the aluminum cylinder, can introduce randomness. Using materials with standardized and well-known properties can help.

During the experiment, there are some parameter that can effeects the results of eperiment, increasing number of turns, N would generally mean that the system undergoes more rotations. In a rotational energy context, this could lead to a higher amount of work done or energy transferred, assuming other factors remain constant. For instance, in experiments involving heat transfer through mechanical work (like friction), more turns could result in greater heat generation. Increasing mass of aluminium cylinder,m might affect the experiment in various ways. For example, if the experiment involves rotational dynamics, a heavier cylinder could change the moment of inertia, potentially affecting the rotational motion. In a thermodynamic context, a larger mass might have a higher heat capacity, affecting how it absorbs or dissipates heat. Increasing mass of weight, M would result in a greater force acting through the same distance, thus increasing the work done. This could lead to more significant energy transfers in the experiment. Increasing the diameter of aluminium cylinder, D could have several effects. If the cylinder is part of a rotational system, a larger radius would increase the moment of inertia, potentially affecting the angular acceleration and rotational kinetic energy. In a heat transfer context, a larger surface area could affect the rate of heat exchange.

Further insights were gained in Experiment B, where J was determined to be 4.918 J/cal, marking a discrepancy of 17.54% from the theoretical value 4.184 J/cal. Lack of temperature control likely led to fluctuations that affected the precision of our temperature measurements, and may have introduced additional uncertainties in the heat transfer processes.

In Part B, the absence of a constant cooling mechanism might have allowed external factors, such as room temperature variations and non-uniform heat losses, to affect the cylinder's temperature, leading to a less accurate calculation of J.

Conversely, in Part A, Likely provided a more accurate value of J due to the controlled temperature conditions. By minimizing external thermal influences, Experiment A ensured that the temperature changes in the cylinder were predominantly due to the work done by friction.

In summary, the discrepancies observed in the values of J across different experimental setups underscore the critical importance of environmental control and the consideration of systematic errors in experimental physics. These factors must be diligently managed to ensure the accuracy and reliability of experimental outcomes in future studies.

Conclusion

In part A experiment, concluded that the mechanical heat equivalent including error is

$$J_s = (4.091 \pm 0.005)\, J/cal$$

In part B experiment, concluded that the mechanical heat equivalent including error is

$$J_T = (4.918 \pm 0.006)\, J/cal$$

In comparision, concluded that the experimetn in part A will produced more accurate result of mechanical heat equivalent due to the less effect of the enviroment temperature.