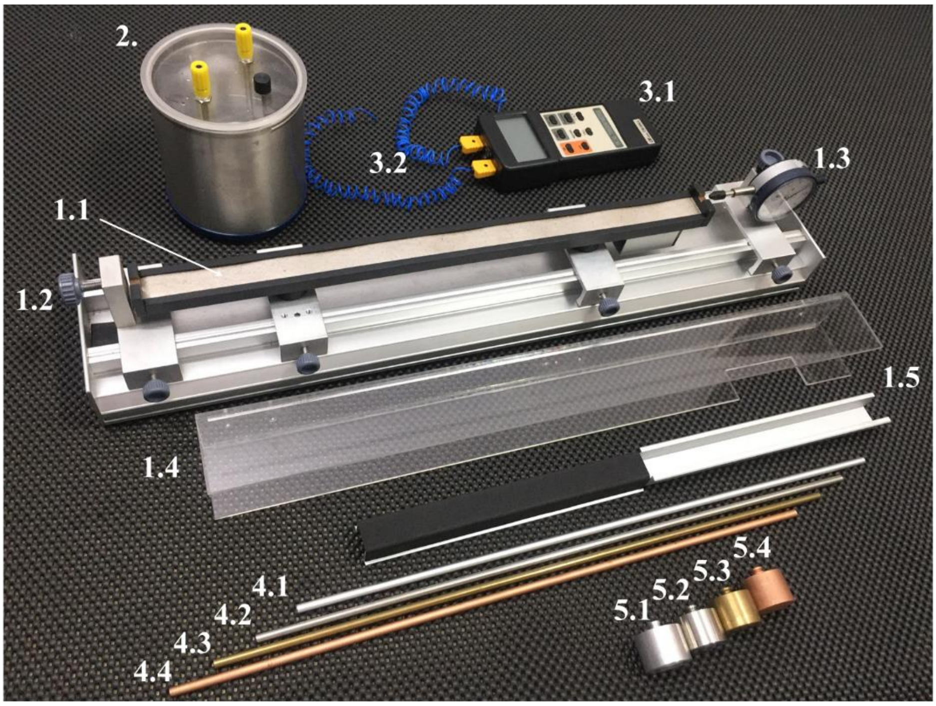
F16 SPECIFIC HEAT, LINEAR THERMAL EXPANSION AND EQUIVALENT OF HEAT

Equipment

1. Aluminum platform x 1
   1.1 Built-in heater
   1.2 Position adjuster
   1.3 Dial indicator
   1.4 Wind shield x 1
   1.5 Thermal insulator x 2
2. Calorimeter with heating wire x 1
3. Thermometer
   3.1 Dual thermometer x 1
   3.2 Thermocouples x 2
4. Metal rods
   4.1 Aluminum alloy (6061) rod x 1
   4.2 Stainless steel (304) rod x 1
   4.3 Brass rod (C3604) x 1
   4.4 Copper (C1100) rod x 1
5. Round metal bars
   5.1 Aluminum alloy (6061) bar x 1
   5.2 Stainless steel (304) bar x 1
   5.3 Brass (C3604) bar x1
   5.4 Copper (C1100) bar x 1

Required but not included in the set

DC/AC power supply x 1
Patch cords x 2
Cotton gloves or tongs
Graduated cylinder



16.1. INTRODUCTION

Thermal Expansion coefficient shows the tendency of matter to change its shape and volume in response to a change in temperature. When a substance is heated, the kinetic energy of its molecule increases. Thus, the molecules begin oscillating faster and more and resulting in greater separation. This resultant relative expansion (also called strain) divided by the change in temperature is called the coefficient of linear thermal expansion (°C) and generally varies with temperature.

$$\alpha = \frac{\Delta l}{l_0 \cdot \Delta T} = \frac{\Delta l}{l_0 \cdot (T_2 - T_1)} \qquad [\frac{1}{°C}] \qquad \textbf{Equation. (1)}$$

Except for few materials contract with increasing temperature, most of the materials including solid, liquid and especially gas will expand after heated up and vice versa after cooled down.

Specific heat, also called *heat capacity*, is a common physical quantity to show an object's ability to absorb or dissipate heat. The bigger the specific heat is, the ability to absorb or dissipate heat will be stronger.

The Si unit of specific heat is joule per degree Celsius and kilogram. For example, at a temperature of 25℃ (the specific heat can vary with the temperature), the heat required to raise the temperature of $1g$ of water by 1℃ is 4.18 joules, meaning that the specific heat of water is $4.18\frac{J}{g \cdot °C}$.

$$Q = m \cdot C \cdot \Delta T = m \cdot C \cdot (T_2 - T_1) \qquad [\frac{J}{g \cdot °C}] \qquad \textbf{Equation. (2)}$$

The concept of *Mechanical Equivalent of Heat* states that mechanical motion and heat are mutually interchangeable and that in every case, a given amount of work would generate the same amount of heat, provided the work done is totally converted to heat energy. This equivalence of heat and motion was showed by Rumford in 1798, as the heat produced by frictional force was proportional to the work done by it.

According to the Energy Conversation Law (The first law of Thermodynamics), the change in internal energy of a system is the sum of the work done and heat added to any system. When work is done on a system is totally transferred into the internal energy (as a heat), the mechanical equivalent of heat is as follows:

$$J = \frac{W}{\Delta H} \qquad [\frac{Joule}{Calorie}] \qquad \textbf{Equation. (3)}$$

Here, the heat can be calculated by *Equation. (1)* as $\Delta H = m \cdot C \cdot \Delta T$

16.2 EXPERIMENTAL SECTION

16.2.1. Linear thermal expansion

16.2.1.1. Procedure
16.2.1.2. Results
16.2.1.3. Reference

16.2.1.1. Procedure

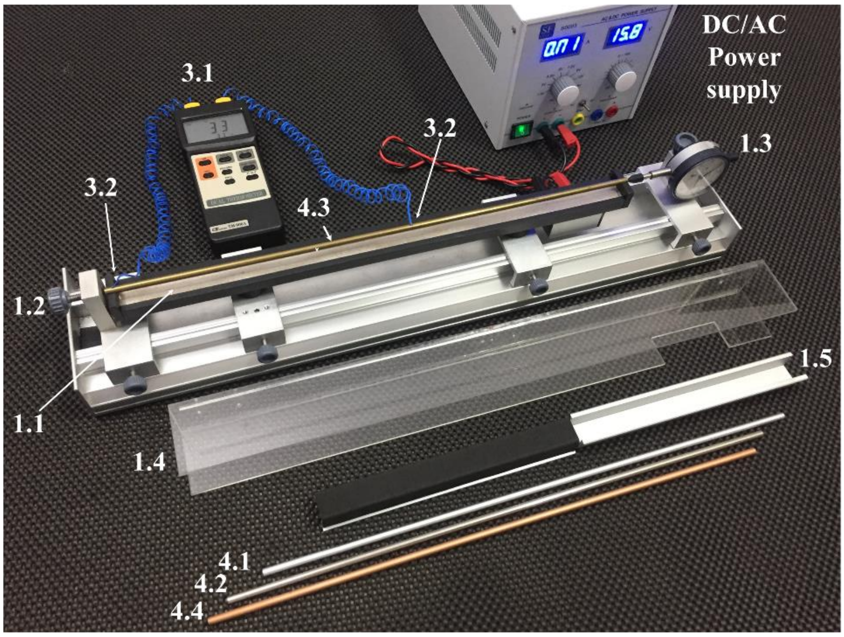
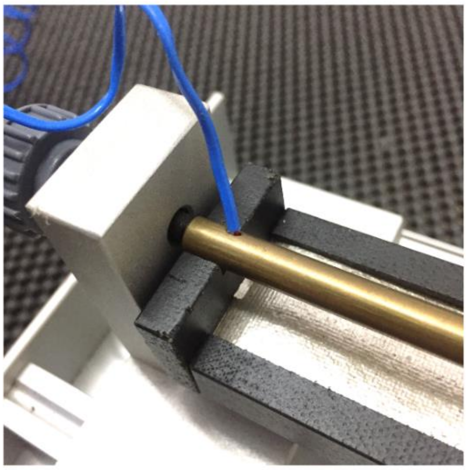
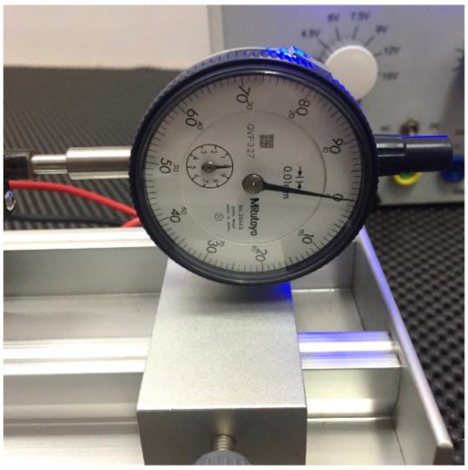


Figure.1 Experimental setup

1. Put a metal rod on the heater (**1.1**) in between position adjuster (**1.2**) and dial indicator (**1.3**) and slowly rotate the adjuster until the indicator points zero.
2. Connect two thermocouples (**3.2**) to two holes on the rod as shown below.

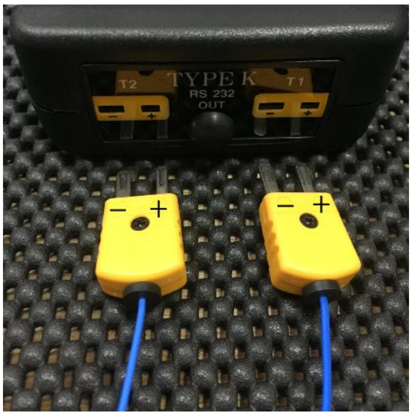
3. Firstly, cover the system by thermal insulator (**1.5**) and then wind shield (**1.4**) to minimize the heat dissipation to the environment.

4. Connect the heater to the DC/AC power supply via patch cords.

> NOTE
>
> Avoid to touching positive terminal to negative one. It will damage the power supply.

5. Turn the power supply on, toggle to AC mode, and increase the current to 5A (0.5V).
6. Record the temperature reading in every 0.02 mm increase in length until the temperature reaches 80℃.

> NOTE
>
> Make sure to connect the positive and negative electrodes properly as shown in the figure.



7. Turn off the heater and use table below to calculate the linear thermal expansion coefficient as follows:

> **<u>Least square method:</u>**
>
> a. Calculate the average temperature of two different area: $T_{average} = \frac{T_1+T_2}{2}$
> b. Deviation of the temperature at i temperature: $\Delta T = T_i - T_0$
> c. Sum the Δl (Y variables) and $l_0 \Delta T$ (X variables) and then calculate the average values.
> d. Calculate $(X - \overline{X})$; $(Y - \overline{Y})$; $(X - \overline{X})^2$; $(Y - \overline{Y})^2$ and $(X - \overline{X})(Y - \overline{Y})$.
> e. Calculate sums of $(X - \overline{X})^2, (Y - \overline{Y})^2$ and $(X - \overline{X})(Y - \overline{Y})$ and note as m, p and n respectively.
> f. Use following equation to obtain "Thermal expansion coefficient (α)":
>
> $y = \alpha x + \beta$ Where: $\alpha = \frac{n}{m}$ and $\beta = \overline{Y} - \alpha \overline{X}$
>
> g. Finally, the coefficient of determination will be calculated as follows:
>
> $$R^2 = \left(\frac{\sum[(X - \overline{X})(Y - \overline{Y})]}{\sqrt{(X - \overline{X})^2 (Y - \overline{Y})^2}}\right)^2$$

8. Wait until the heater completely cools down and repeat *(1)-(7)* with another metal rods.
9. Use software and "Least square method" to calculate the coefficient and compare with the theoretical values (See *16.2.3.4 Appendix*).

16.2.1.2. Results

Aluminum alloy rod $\boldsymbol{l_0}$ = _____ mm $\boldsymbol{T_0}$ = _____℃

	$\Delta \boldsymbol{l}$, $\boldsymbol{mm}$	$\boldsymbol{T_1}$, ℃	$\boldsymbol{T_2}$, ℃	$\boldsymbol{T_{average}}$, ℃	$\Delta \boldsymbol{T}$, ℃	$\boldsymbol{l_0 \Delta T}$	$(\boldsymbol{X}-\overline{X})$	$(\boldsymbol{Y}-\overline{Y})$	$(\boldsymbol{X}-\overline{X})^2$	$(\boldsymbol{Y}-\overline{Y})^2$	$(\boldsymbol{X}-\overline{X})(\boldsymbol{Y}-\overline{Y})$
Sum									$\boldsymbol{m}$=	$\boldsymbol{p}$=	$\boldsymbol{n}$=
Mean	$\overline{Y}$=					$\overline{X}$=					

Thermal expansion equation:

$$\boldsymbol{y = \alpha x + \beta}$$

Where: $\boldsymbol{\alpha = \frac{n}{m}}$ **and** $\boldsymbol{\beta} = \overline{Y} - \alpha \overline{X}$ ***and*** $\boldsymbol{\alpha}$: is the “Linear thermal expansion coefficient”

$$\boldsymbol{R^2} = \left(\frac{\sum[(\boldsymbol{X}-\overline{X})(\boldsymbol{Y}-\overline{Y})]}{\sqrt{(\boldsymbol{X}-\overline{X})^2(\boldsymbol{Y}-\overline{Y})^2}}\right)^{\boldsymbol{2}}$$

Stainless steel rod $\boldsymbol{l_0} =$ _____ mm $\boldsymbol{T_0} =$ _____℃

	$\Delta \boldsymbol{l}$, $\boldsymbol{mm}$	$\boldsymbol{T_1}$, ℃	$\boldsymbol{T_2}$, ℃	$\boldsymbol{T_{average}}$, ℃	$\Delta \boldsymbol{T}$, ℃	$\boldsymbol{l_0}\Delta\boldsymbol{T}$	$(\boldsymbol{X}-\overline{X})$	$(\boldsymbol{Y}-\overline{Y})$	$(\boldsymbol{X}-\overline{X})^2$	$(\boldsymbol{Y}-\overline{Y})^2$	$(\boldsymbol{X}-\overline{X})(\boldsymbol{Y}-\overline{Y})$
Sum									$\boldsymbol{m}$=	$\boldsymbol{p}$=	$\boldsymbol{n}$=
Mean	$\overline{\boldsymbol{Y}}$=					$\overline{\boldsymbol{X}}$=					

Thermal expansion equation:

$\boldsymbol{y = \alpha x + \beta}$

Where: $\boldsymbol{\alpha = \frac{n}{m}}$ **and** $\boldsymbol{\beta} = \overline{Y} - \alpha\overline{X}$ ***and*** $\boldsymbol{\alpha}$: is the “Linear thermal expansion coefficient”

$$\boldsymbol{R^2} = \left(\frac{\sum[(\boldsymbol{X}-\overline{X})(\boldsymbol{Y}-\overline{Y})]}{\sqrt{(\boldsymbol{X}-\overline{X})^2(\boldsymbol{Y}-\overline{Y})^2}}\right)^{\boldsymbol{2}}$$

Brass rod $\boldsymbol{l_0} =$ _____ mm $\boldsymbol{T_0} =$ _____℃

	$\Delta\boldsymbol{l}$, $\boldsymbol{mm}$	$\boldsymbol{T_1}$, ℃	$\boldsymbol{T_2}$, ℃	$\boldsymbol{T_{average}}$, ℃	$\Delta\boldsymbol{T}$, ℃	$\boldsymbol{l_0}\Delta\boldsymbol{T}$	$(\boldsymbol{X}-\overline{X})$	$(\boldsymbol{Y}-\overline{Y})$	$(\boldsymbol{X}-\overline{X})^2$	$(\boldsymbol{Y}-\overline{Y})^2$	$(\boldsymbol{X}-\overline{X})(\boldsymbol{Y}-\overline{Y})$
Sum									$\boldsymbol{m}$=	$\boldsymbol{p}$=	$\boldsymbol{n}$=
Mean	$\overline{Y}$=					$\overline{X}$=					

Thermal expansion equation:

$$\boldsymbol{y = \alpha x + \beta}$$

Where: $\boldsymbol{\alpha} = \frac{\boldsymbol{n}}{\boldsymbol{m}}$ **and** $\boldsymbol{\beta} = \overline{Y} - \boldsymbol{\alpha}\overline{X}$ ***and*** $\boldsymbol{\alpha}$: is the “Linear thermal expansion coefficient”

$$\boldsymbol{R^2} = \left(\frac{\sum[(\boldsymbol{X}-\overline{X})(\boldsymbol{Y}-\overline{Y})]}{\sqrt{(\boldsymbol{X}-\overline{X})^2(\boldsymbol{Y}-\overline{Y})^2}}\right)^2$$

Copper rod $\boldsymbol{l_0} =$ _____ mm $\boldsymbol{T_0} =$ _____℃

	$\Delta\boldsymbol{l}$, $\boldsymbol{mm}$	$\boldsymbol{T_1}$, ℃	$\boldsymbol{T_2}$, ℃	$\boldsymbol{T_{average}}$, ℃	$\Delta\boldsymbol{T}$, ℃	$\boldsymbol{l_0}\Delta\boldsymbol{T}$	$(\boldsymbol{X}-\overline{X})$	$(\boldsymbol{Y}-\overline{Y})$	$(\boldsymbol{X}-\overline{X})^2$	$(\boldsymbol{Y}-\overline{Y})^2$	$(\boldsymbol{X}-\overline{X})(\boldsymbol{Y}-\overline{Y})$
Sum									$\boldsymbol{m}$=	$\boldsymbol{p}$=	$\boldsymbol{n}$=
Mean	$\overline{Y}$=					$\overline{X}$=					

Thermal expansion equation:

$$\boldsymbol{y = \alpha x + \beta}$$

Where: $\boldsymbol{\alpha = \frac{n}{m}}$ **and** $\boldsymbol{\beta} = \overline{Y} - \alpha\overline{X}$ ***and*** $\boldsymbol{\alpha}$: is the “Linear thermal expansion coefficient”

$$\boldsymbol{R^2} = \left(\frac{\sum[(\boldsymbol{X}-\overline{X})(\boldsymbol{Y}-\overline{Y})]}{\sqrt{(\boldsymbol{X}-\overline{X})^2(\boldsymbol{Y}-\overline{Y})^2}}\right)^{\boldsymbol{2}}$$

16.2.1.3. Reference

Aluminum alloy rod

Initial length of the rod ($\boldsymbol{l_0} = 460\ mm$) Temperature of the rod ($\boldsymbol{T_0} = 32$℃)

	$\Delta l, mm$	T_1, ℃	T_2, ℃	$T_{average}$, ℃	ΔT, ℃	$l_0 \Delta T$	$(X-\overline{X})$	$(Y-\overline{Y})$	$(X-\overline{X})^2$	$(Y-\overline{Y})^2$	$(X-\overline{X})(Y-\overline{Y})$
	0.01	33	33	33	1	460	-8635.8491	-0.26	74577888.93	0.0676	2245.320755
	0.02	34	35	34.5	2.5	1150	-7945.8491	-0.25	63136517.23	0.0625	1986.462264
	0.03	35	36	35.5	3.5	1610	-7485.8491	-0.24	56037936.1	0.0576	1796.603774
	0.04	36	37	36.5	4.5	2070	-7025.8491	-0.23	49362554.97	0.0529	1615.945283
	0.05	36	38	37	5	2300	-6795.8491	-0.22	46183564.4	0.0484	1495.086792
	0.06	37	39	38	6	2760	-6335.8491	-0.21	40142983.27	0.0441	1330.528302
	0.07	38	40	39	7	3220	-5875.8491	-0.2	34525602.14	0.04	1175.169811
	0.08	39	41	40	8	3680	-5415.8491	-0.19	29331421	0.0361	1029.011321
	0.09	39	42	40.5	8.5	3910	-5185.8491	-0.18	26893030.44	0.0324	933.4528302
	0.1	40	43	41.5	9.5	4370	-4725.8491	-0.17	22333649.31	0.0289	803.3943396
	0.11	41	44	42.5	10.5	4830	-4265.8491	-0.16	18197468.17	0.0256	682.5358491
	0.12	42	44	43	11	5060	-4035.8491	-0.15	16288077.61	0.0225	605.3773585
	0.13	43	46	44.5	12.5	5750	-3345.8491	-0.14	11194705.91	0.0196	468.4188679
	0.14	43	47	45	13	5980	-3115.8491	-0.13	9708515.344	0.0169	405.0603774
	0.15	44	47	45.5	13.5	6210	-2885.8491	-0.12	8328124.778	0.0144	346.3018868
	0.16	45	48	46.5	14.5	6670	-2425.8491	-0.11	5884743.645	0.0121	266.8433962
	0.17	46	50	48	16	7360	-1735.8491	-0.1	3013171.947	0.01	173.5849057
	0.18	47	50	48.5	16.5	7590	-1505.8491	-0.09	2267581.381	0.0081	135.5264151
	0.19	48	51	49.5	17.5	8050	-1045.8491	-0.08	1093800.249	0.0064	83.66792453
	0.2	48	52	50	18	8280	-815.84906	-0.07	665609.6832	0.0049	57.10943396
	0.21	49	52	50.5	18.5	8510	-585.84906	-0.06	343219.1171	0.0036	35.1509434
	0.22	50	53	51.5	19.5	8970	-125.84906	-0.05	15837.98505	0.0025	6.29245283
	0.23	51	54	52.5	20.5	9430	334.15094	-0.04	111656.853	0.0016	-13.36603774
	0.24	52	56	54	22	10120	1024.1509	-0.03	1048885.155	0.0009	-30.7245283
	0.25	52	57	54.5	22.5	10350	1254.1509	-0.02	1572894.589	0.0004	-25.08301887
	0.26	53	57	55	23	10580	1484.1509	-0.01	2202704.023	0.0001	-14.84150943
	0.27	54	58	56	24	11040	1944.1509	0	3779722.891	0	0
	0.28	55	59	57	25	11500	2404.1509	0.01	5779941.759	0.0001	24.04150943
	0.29	56	60	58	26	11960	2864.1509	0.02	8203360.627	0.0004	57.28301887
	0.3	57	60	58.5	26.5	12190	3094.1509	0.03	9573770.061	0.0009	92.8245283
	0.31	58	61	59.5	27.5	12650	3554.1509	0.04	12631988.93	0.0016	142.1660377
	0.32	58	62	60	28	12880	3784.1509	0.05	14319798.36	0.0025	189.2075472
	0.33	59	63	61	29	13340	4244.1509	0.06	18012817.23	0.0036	254.6490566
	0.34	60	64	62	30	13800	4704.1509	0.07	22129036.1	0.0049	329.290566
	0.35	60	65	62.5	30.5	14030	4934.1509	0.08	24345845.53	0.0064	394.7320755
	0.36	61	66	63.5	31.5	14490	5394.1509	0.09	29096864.4	0.0081	485.4735849
	0.37	62	67	64.5	32.5	14950	5854.1509	0.1	34271083.27	0.01	585.4150943
	0.38	63	67	65	33	15180	6084.1509	0.11	37016892.7	0.0121	669.2566038
	0.39	64	69	66.5	34.5	15870	6774.1509	0.12	45889121	0.0144	812.8981132
	0.4	65	69	67	35	16100	7004.1509	0.13	49058130.44	0.0169	910.5396226
	0.41	65	70	67.5	35.5	16330	7234.1509	0.14	52332939.87	0.0196	1012.781132
	0.42	66	72	69	37	17020	7924.1509	0.15	62792168.17	0.0225	1188.622642
	0.43	67	72	69.5	37.5	17250	8154.1509	0.16	66490177.61	0.0256	1304.664151
	0.44	68	73	70.5	38.5	17710	8614.1509	0.17	74203596.48	0.0289	1464.40566
	0.45	69	74	71.5	39.5	18170	9074.1509	0.18	82340215.34	0.0324	1633.34717
	0.46	70	74	72	40	18400	9304.1509	0.19	86567224.78	0.0361	1767.788679
	0.47	71	75	73	41	18860	9764.1509	0.2	95338643.65	0.04	1952.830189
	0.48	71	76	73.5	41.5	19090	9994.1509	0.21	99883053.08	0.0441	2098.771698
	0.49	72	77	74.5	42.5	19550	10454.151	0.22	109289271.9	0.0484	2299.913208
	0.5	73	77	75	43	19780	10684.151	0.23	114151081.4	0.0529	2457.354717
	0.51	74	78	76	44	20240	11144.151	0.24	124192100.2	0.0576	2674.596226
	0.52	74	79	76.5	44.5	20470	11374.151	0.25	129371309.7	0.0625	2843.537736
	0.53	75	80	77.5	45.5	20930	11834.151	0.26	140047128.6	0.0676	3076.879245
SUM	**14.31**					**482080**			**2075569428**	**1.2402**	**48316.1**
Mean	**0.27**					**9095.849**					

$\alpha = \frac{n}{m} = \frac{48316.1}{2075569428} = 2.32785 * 10^{-5}$ and;

$\beta = \overline{Y} - \alpha\overline{X} = 0.27 - 2.32785 * 10^{-5} * 9095.8491 = 0.058262466$

Finally, $y = 2.32785 * 10^{-5}x + 0.058262466$

Where: α: is the "Linear thermal expansion coefficient"

$R^2 = (\frac{n}{\sqrt{m*p}})^2 = (\frac{48316.1}{\sqrt{2075569428*1.2402}})^2 = 0.907$

Theoretical coefficient: $2.36 * 10^{-5}$, ℃$^{-1}$

The error of the experiment: $= \frac{|Theoretical\ value - Experimental\ value|}{Theoretical\ value} * 100\% = 1.69\%$

Stainless steel rod

Initial length of the rod ($\boldsymbol{l_0} = 460\ mm$) Temperature of the rod ($\boldsymbol{T_0} = 32$°C)

	$\Delta l, mm$	T_1, °C	T_2, °C	$T_{average}$, °C	ΔT, °C	$l_0 \Delta T$	$(X-\overline{X})$	$(Y-\overline{Y})$	$(X-\overline{X})^2$	$(Y-\overline{Y})^2$	$(X-\overline{X})(Y-\overline{Y})$
	0.01	32	33	32.5	0.5	230	-10528.889	-0.175	110857501.2	0.030625	1842.556
	0.02	33	34	33.5	1.5	690	-10068.889	-0.165	101382523.5	0.027225	1661.367
	0.03	35	36	35.5	3.5	1610	-9148.8889	-0.155	83702167.9	0.024025	1418.078
	0.04	36	38	37	5	2300	-8458.8889	-0.145	71552801.23	0.021025	1226.539
	0.05	38	40	39	7	3220	-7538.8889	-0.135	56834845.68	0.018225	1017.750
	0.06	39	41	40	8	3680	-7078.8889	-0.125	50110667.9	0.015625	884.861
	0.07	40	43	41.5	9.5	4370	-6388.8889	-0.115	40817901.23	0.013225	734.722
	0.08	41	44	42.5	10.5	4830	-5928.8889	-0.105	35151723.46	0.011025	622.533
	0.09	43	46	44.5	12.5	5750	-5008.8889	-0.095	25088967.9	0.009025	475.844
	0.1	44	47	45.5	13.5	6210	-4548.8889	-0.085	20692390.12	0.007225	386.656
	0.11	45	48	46.5	14.5	6670	-4088.8889	-0.075	16719012.35	0.005625	306.667
	0.12	46	50	48	16	7360	-3398.8889	-0.065	11552445.68	0.004225	220.928
	0.13	47	51	49	17	7820	-2938.8889	-0.055	8637067.901	0.003025	161.639
	0.14	48	52	50	18	8280	-2478.8889	-0.045	6144890.123	0.002025	111.550
	0.15	49	54	51.5	19.5	8970	-1788.8889	-0.035	3200123.457	0.001225	62.611
	0.16	50	56	53	21	9660	-1098.8889	-0.025	1207556.79	0.000625	27.472
	0.17	51	56	53.5	21.5	9890	-868.88889	-0.015	754967.9012	0.000225	13.033
	0.18	52	58	55	23	10580	-178.88889	-0.005	32001.23457	0.000025	0.894
	0.19	53	59	56	24	11040	281.11111	0.005	79023.45679	0.000025	1.406
	0.2	54	61	57.5	25.5	11730	971.11111	0.015	943056.7901	0.000225	14.567
	0.21	56	62	59	27	12420	1661.1111	0.025	2759290.123	0.000625	41.528
	0.22	57	63	60	28	12880	2121.1111	0.035	4499112.346	0.001225	74.239
	0.23	58	65	61.5	29.5	13570	2811.1111	0.045	7902345.679	0.002025	126.500
	0.24	59	66	62.5	30.5	14030	3271.1111	0.055	10700167.9	0.003025	179.911
	0.25	60	67	63.5	31.5	14490	3731.1111	0.065	13921190.12	0.004225	242.522
	0.26	61	68	64.5	32.5	14950	4191.1111	0.075	17565412.35	0.005625	314.333
	0.27	62	70	66	34	15640	4881.1111	0.085	23825245.68	0.007225	414.894
	0.28	63	71	67	35	16100	5341.1111	0.095	28527467.9	0.009025	507.406
	0.29	64	73	68.5	36.5	16790	6031.1111	0.105	36374301.23	0.011025	633.267
	0.3	65	74	69.5	37.5	17250	6491.1111	0.115	42134523.46	0.013225	746.478
	0.31	66	75	70.5	38.5	17710	6951.1111	0.125	48317945.68	0.015625	868.889
	0.32	67	76	71.5	39.5	18170	7411.1111	0.135	54924567.9	0.018225	1000.500
	0.33	68	77	72.5	40.5	18630	7871.1111	0.145	61954390.12	0.021025	1141.311
	0.34	69	79	74	42	19320	8561.1111	0.155	73292623.46	0.024025	1326.972
	0.35	71	80	75.5	43.5	20010	9251.1111	0.165	85583056.79	0.027225	1526.433
	0.36	72	81	76.5	44.5	20470	9711.1111	0.175	94305679.01	0.030625	1699.444
SUM	**6.66**					**387320**			**1252048956**	**0.3885**	**22036.3**
Mean	**0.185**					**10758.89**					

$\alpha = \frac{n}{m} = \frac{22036.3}{1252048956} = 1.76 * 10^{-5}$ and;

$\beta = \overline{Y} - \alpha\overline{X} = 0.185 - 1.76 * 10^{-5} * 10758.889 = -0.004358493$

Finally, $y = 1.76 * 10^{-5}x - 0.004358493$

Where: α: is the “Linear thermal expansion coefficient”

$R^2 = (\frac{n}{\sqrt{m*p}})^2 = (\frac{22036.3}{\sqrt{1252048956*0.3885}})^2 = 0.998$

Theoretical coefficient: $1.73 * 10^{-5}, \text{°C}^{-\mathbf{1}}$

The error of the experiment: $= \frac{|Theoretical\ value - Experimental\ value|}{Theoretical\ value} * 100\% = 1.73\%$

Brass rod

Initial length of the rod ($\boldsymbol{l_0} = 460\ mm$)   Temperature of the rod ($\boldsymbol{T_0} = 32$℃)

	$\Delta l, mm$	T_1, ℃	T_2, ℃	$T_{average}$, ℃	ΔT, ℃	$l_0 \Delta T$	$(X-\overline{X})$	$(Y-\overline{Y})$	$(X-\overline{X})^2$	$(Y-\overline{Y})^2$	$(X-\overline{X})(Y-\overline{Y})$
	0.01	33	33	33	1	460	-10563.171	-0.2	111580575.9	0.04	2112.634146
	0.02	34	35	34.5	2.5	1150	-10103.171	-0.19	102074058.8	0.0361	1919.602439
	0.03	35	36	35.5	3.5	1610	-9413.1707	-0.18	88607783.22	0.0324	1694.370732
	0.04	36	37	36.5	4.5	2070	-8953.1707	-0.17	80159266.15	0.0289	1522.039024
	0.05	37	39	38	6	2760	-8493.1707	-0.16	72133949.08	0.0256	1358.907317
	0.06	38	40	39	7	3220	-7803.1707	-0.15	60889473.47	0.0225	1170.47561
	0.07	39	41	40	8	3680	-7343.1707	-0.14	53922156.4	0.0196	1028.043902
	0.08	40	43	41.5	9.5	4370	-6883.1707	-0.13	47378039.32	0.0169	894.8121951
	0.09	41	44	42.5	10.5	4830	-6193.1707	-0.12	38355363.71	0.0144	743.1804878
	0.1	42	45	43.5	11.5	5290	-5733.1707	-0.11	32869246.64	0.0121	630.6487805
	0.11	43	46	44.5	12.5	5750	-5273.1707	-0.1	27806329.57	0.01	527.3170732
	0.12	44	48	46	14	6440	-4813.1707	-0.09	23166612.49	0.0081	433.1853659
	0.13	44	48	46	14	6440	-4123.1707	-0.08	17000536.88	0.0064	329.8536585
	0.14	45	49	47	15	6900	-4123.1707	-0.07	17000536.88	0.0049	288.6219512
	0.15	46	50	48	16	7360	-3663.1707	-0.06	13418819.81	0.0036	219.7902439
	0.16	47	51	49	17	7820	-3203.1707	-0.05	10260302.74	0.0025	160.1585366
	0.17	48	53	50.5	18.5	8510	-2743.1707	-0.04	7524985.663	0.0016	109.7268293
	0.18	50	54	52	20	9200	-2053.1707	-0.03	4215510.054	0.0009	61.59512195
	0.19	51	55	53	21	9660	-1363.1707	-0.02	1858234.444	0.0004	27.26341463
	0.2	52	57	54.5	22.5	10350	-903.17073	-0.01	815717.3706	1E-04	9.031707317
	0.21	53	58	55.5	23.5	10810	-213.17073	0	45441.76086	0	0
	0.22	54	59	56.5	24.5	11270	246.82927	0.01	60924.68769	0.0001	2.468292683
	0.23	54	60	57	25	11500	706.82927	0.02	499607.6145	0.0004	14.13658537
	0.24	55	61	58	26	11960	936.82927	0.03	877649.0779	0.0009	28.10487805
	0.25	56	62	59	27	12420	1396.8293	0.04	1951132.005	0.0016	55.87317073
	0.26	58	63	60.5	28.5	13110	1856.8293	0.05	3447814.932	0.0025	92.84146341
	0.27	59	64	61.5	29.5	13570	2546.8293	0.06	6486339.322	0.0036	152.8097561
	0.28	59	66	62.5	30.5	14030	3006.8293	0.07	9041022.249	0.0049	210.4780488
	0.29	60	66	63	31	14260	3466.8293	0.08	12018905.18	0.0064	277.3463415
	0.3	61	67	64	32	14720	3696.8293	0.09	13666546.64	0.0081	332.7146341
	0.31	62	69	65.5	33.5	15410	4156.8293	0.1	17279229.57	0.01	415.6829268
	0.32	63	70	66.5	34.5	15870	4846.8293	0.11	23491753.96	0.0121	533.1512195
	0.33	65	71	68	36	16560	5306.8293	0.12	28162436.88	0.0144	636.8195122
	0.34	65	74	69.5	37.5	17250	5996.8293	0.13	35961961.27	0.0169	779.5878049
	0.35	65	74	69.5	37.5	17250	6686.8293	0.14	44713685.66	0.0196	936.1560976
	0.36	68	74	71	39	17940	6686.8293	0.15	44713685.66	0.0225	1003.02439
	0.37	69	75	72	40	18400	7376.8293	0.16	54417610.05	0.0256	1180.292683
	0.38	70	77	73.5	41.5	19090	7836.8293	0.17	61415892.98	0.0289	1332.260976
	0.39	71	77	74	42	19320	8526.8293	0.18	72706817.37	0.0324	1534.829268
	0.4	72	79	75.5	43.5	20010	8756.8293	0.19	76682058.83	0.0361	1663.797561
	0.41	73	80	76.5	44.5	20470	9446.8293	0.2	89242583.22	0.04	1889.365854
SUM	**8.61**					**433090**			**1407920598**	**0.574**	**28313**
Mean	**0.21**					**10563.17**					

$\alpha = \frac{n}{m} = \frac{28313}{1407920598} = 2.01 * 10^{-5}$ and;

$\beta = \overline{Y} - \alpha\overline{X} = 0.21 - 2.01 * 10^{-5} * 10563.171 = -0.002423239$

Finally, $y = 2.01 * 10^{-5}x - 0.002423239$

Where: α: is the "Linear thermal expansion coefficient"

$R^2 = (\frac{n}{\sqrt{m*p}})^2 = (\frac{28313}{\sqrt{1407920598*0.574}})^2 = 0.992$

Theoretical coefficient: $2.05 * 10^{-5}$, $℃^{-1}$

The error of the experiment: $= \frac{|Theoretical\ value - Experimental\ value|}{Theoretical\ value} * 100\% = 1.9\%$

Copper rod

Initial length of the rod ($\boldsymbol{l_0} = 460\ mm$)   Temperature of the rod ($\boldsymbol{T_0} = 32$°C)

	$\Delta l, mm$	T_1, °C	T_2, °C	$T_{average}$, °C	ΔT, °C	$l_0 \Delta T$	$(X-\overline{X})$	$(Y-\overline{Y})$	$(X-\overline{X})^2$	$(Y-\overline{Y})^2$	$(X-\overline{X})(Y-\overline{Y})$
	0.01	36	36	36	4	1840	-14703.953	-0.21	216206248.2	0.0441	3087.830233
	0.02	37	38	37.5	5.5	2530	-12863.953	-0.25	165481299.4	0.0625	3215.988372
	0.03	40	40	40	8	3680	-12173.953	-0.24	148205143.5	0.0576	2921.748837
	0.04	41	41	41	9	4140	-11023.953	-0.23	121527550.5	0.0529	2535.509302
	0.05	42	43	42.5	10.5	4830	-10563.953	-0.22	111597113.3	0.0484	2324.069767
	0.06	44	44	44	12	5520	-9873.9535	-0.21	97494957.49	0.0441	2073.530233
	0.07	45	46	45.5	13.5	6210	-9183.9535	-0.2	84345001.68	0.04	1836.790698
	0.08	47	47	47	15	6900	-8493.9535	-0.19	72147245.86	0.0361	1613.851163
	0.09	48	49	48.5	16.5	7590	-7803.9535	-0.18	60901690.05	0.0324	1404.711628
	0.1	50	50	50	18	8280	-7113.9535	-0.17	50608334.23	0.0289	1209.372093
	0.11	51	52	51.5	19.5	8970	-6423.9535	-0.16	41267178.42	0.0256	1027.832558
	0.12	52	53	52.5	20.5	9430	-5733.9535	-0.15	32878222.61	0.0225	860.0930233
	0.13	54	54	54	22	10120	-5273.9535	-0.14	27814585.4	0.0196	738.3534884
	0.14	55	55	55	23	10580	-4583.9535	-0.13	21012629.58	0.0169	595.9139535
	0.15	56	56	56	24	11040	-4123.9535	-0.12	17006992.37	0.0144	494.8744186
	0.16	57	57	57	25	11500	-3663.9535	-0.11	13424555.16	0.0121	403.0348837
	0.17	58	59	58.5	26.5	12190	-3203.9535	-0.1	10265317.96	0.01	320.3953488
	0.18	59	60	59.5	27.5	12650	-2513.9535	-0.09	6319962.142	0.0081	226.255814
	0.19	61	61	61	29	13340	-2053.9535	-0.08	4218724.932	0.0064	164.3162791
	0.2	62	62	62	30	13800	-1363.9535	-0.07	1860369.118	0.0049	95.47674419
	0.21	63	63	63	31	14260	-903.95349	-0.06	817131.9091	0.0036	54.2372093
	0.22	64	65	64.5	32.5	14950	-443.95349	-0.05	197094.6998	0.0025	22.19767442
	0.23	66	67	66.5	34.5	15870	246.04651	-0.04	60538.88588	0.0016	-9.841860465
	0.24	66	67	66.5	34.5	15870	1166.0465	-0.03	1359664.467	0.0009	-34.98139535
	0.25	67	68	67.5	35.5	16330	1166.0465	-0.02	1359664.467	0.0004	-23.32093023
	0.26	69	69	69	37	17020	1626.0465	-0.01	2644027.258	0.0001	-16.26046512
	0.27	70	71	70.5	38.5	17710	2316.0465	0	5364071.444	0	0
	0.28	71	72	71.5	39.5	18170	3006.0465	0.01	9036315.63	0.0001	30.06046512
	0.29	72	73	72.5	40.5	18630	3466.0465	0.02	12013478.42	0.0004	69.32093023
	0.3	74	75	74.5	42.5	19550	3926.0465	0.03	15413841.21	0.0009	117.7813953
	0.31	75	76	75.5	43.5	20010	4846.0465	0.04	23484166.79	0.0016	193.8418605
	0.32	76	77	76.5	44.5	20470	5306.0465	0.05	28154129.58	0.0025	265.3023256
	0.33	77	77	77	45	20700	5766.0465	0.06	33247292.37	0.0036	345.9627907
	0.34	78	79	78.5	46.5	21390	5996.0465	0.07	35952573.77	0.0049	419.7232558
	0.35	78	80	79	47	21620	6686.0465	0.08	44703217.96	0.0064	534.8837209
	0.36	80	82	81	49	22540	6916.0465	0.09	47831699.35	0.0081	622.444186
	0.37	82	83	82.5	50.5	23230	7836.0465	0.1	61403624.93	0.01	783.6046512
	0.38	83	85	84	52	23920	8526.0465	0.11	72693469.12	0.0121	937.8651163
	0.39	84	85	84.5	52.5	24150	9216.0465	0.12	84935513.3	0.0144	1105.925581
	0.4	85	86	85.5	53.5	24610	9446.0465	0.13	89227794.7	0.0169	1227.986047
	0.41	86	87	86.5	54.5	25070	9906.0465	0.14	98129757.49	0.0196	1386.846512
	0.42	87	88	87.5	55.5	25530	10366.047	0.15	107454920.3	0.0225	1554.906977
	0.43	87	88	87.5	55.5	25530	10826.047	0.16	117203283.1	0.0256	1732.167442
SUM	**9.46**					**632270**			**2197270393**	**0.7462**	**38470.60233**
Mean	**0.22**					**14703.95**					

$\alpha = \frac{n}{m} = \frac{36847.060233}{2197270393} = 1.7508 * 10^{-5}$ and;

$\beta = \overline{Y} - \alpha\overline{X} = 0.22 - \mathbf{1.7508 * 10^{-5}} * 14703.95349 = \mathbf{-0.03744212}$

Finally, $y = 1.7508 * 10^{-5}x - 0.03744212$

Where: α: is the "Linear thermal expansion coefficient"

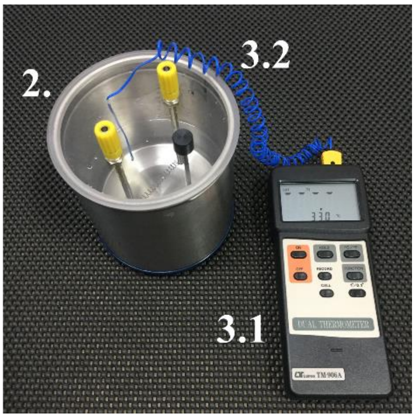
$R^2 = (\frac{n}{\sqrt{m*p}})^2 = (\frac{38470.60233}{\sqrt{2197270393*0.7462}})^2 = 0.902$

Theoretical coefficient: $1.77 * 10^{-5}$, °$\mathrm{C}^{-\mathbf{1}}$

The error of the experiment: $= \frac{|Theoretical\ value - Experimental\ value|}{Theoretical\ value} * 100\% = 1.13\%$

16.2.2. Specific heat

16.2.2.1. Procedure



> NOTE
>
> When dipping the thermocouple tip into the water, please avoid touching the bottom. It must be measuring the water temperature not any metal surface.

A. Specific heat of the calorimeter

1. Using a graduated cylinder, measure $200\,mL$ of water. Pour the water into the calorimeter (**2.**). Close the lid and dip a thermocouple (**3.2.**) into the water as it is passing through the lid.

> NOTE
>
> The volume is directly converted into the mass since, the water density at $25°C$ is $0.997\,\frac{g}{m^3}$, which is almost equal to $1\,\frac{g}{m^3}$.

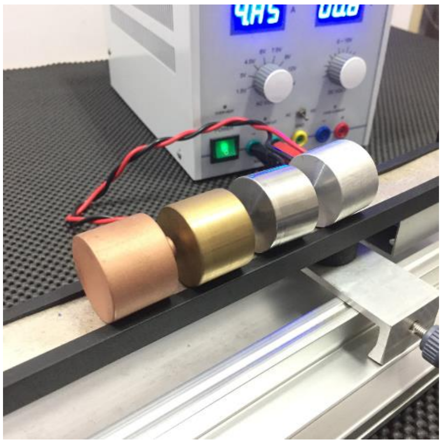
2. Turn on the thermometer (**3.1.**) to measure the temperature of the water in the calorimeter until the temperature is steady and record this temperature as T_{cold}.
3. Measure $200\,mL$ of hot water using a graduated cylinder. Wait until the temperature of the water to approximately $20°C$ above room temperature. When the temperature of the hot water is approximately constant, measure and record this temperature as T_{hot}.
4. Pour the hot water quickly into the calorimeter and replace the lid. Dip the thermocouple and stir gently by swirling the calorimeter. Observe the temperature rise and record the maximum temperature reached as T_{final}.
5. Empty the calorimeter and calculate the specific heat of the calorimeter.

B. Specific heat of the metal bars

1. Make sure you have carried out *Part.A* and determined the specific heat of the calorimeter beforehand.

2. Using a graduated cylinder, measure $200\ mL$ of distilled water. Pour the water into the calorimeter. Close the lid and dip a thermocouple. Turn on the thermometer to measure the temperature of the water until the temperature is steady. Calculate the average and record this temperature as $T_{cal}^{initial}$.

3. Heat up a metal bar on the heater of the aluminum platform to approximately $80°C$.



NOTE

Use tongs or wear cotton gloves to handle the bar when it is heated. Avoid touching the heater when it is on

4. Carefully remove the bar from the heater and allow it to stand a minute or so. When the temperature of the hot bar is approximately constant, measure and record this temperature as $T_{bar}^{initial}$.

5. Immerse the hot bar quickly into the calorimeter and replace the lid. Dip the thermocouple and stir gently by swirling the calorimeter. Observe the temperature rise with high accuracy ($0.1°C$) and record the maximum temperature reached as T_{final}.

6. Empty the calorimeter and calculate the specific heat and compare with the theoretical values (See *16.2.3.4 Appendix*).

7. Repeat *(2)-(6)* with another three metal bars.

16.2.2.2. Results

A. Empty calorimeters specific heat.

$T_{cold} =$ $\quad\quad$ $T_{hot} =$ $\quad\quad$ $T_{final} =$

$\Delta T_{cold} =$ $\quad\quad$ $\Delta T_{hot} =$

Specific heat of the water: $C_{water} = 4.18 \frac{J}{g \cdot ℃}$

$Q_{cal} = -Q_{hot} - Q_{cold}$

$Q_{cold} = m_{cold} \cdot C_{water} \cdot \Delta T_{cold} =$

$Q_{hot} = m_{hot} \cdot C_{water} \cdot \Delta T_{hot} =$

NOTE: Remember the calorimeter includes the $400\ g$ of water so we must include the heat capacity of this much water

$m_{water} = m_{cold} + m_{hot}$

$C_{cal} = m_{cal} \frac{Q_{cal}}{\Delta T} + C_{water} \cdot m_{water} =$

B. Materials specific heat

Specific heat of the system: $C_{cal} =$

$Q_{cal} = -Q_{bar}$, it gives:

$m_{cal} \cdot C_{cal} \cdot (T^{final} - T_{cal}^{initial}) = m_{bar} \cdot C_{bar} \cdot (T^{final} - T_{bar}^{initial})$

Metal	$\boldsymbol{T_{cal}^{initial}}$, ℃	$\boldsymbol{m_{bar}}$, $\boldsymbol{g}$	$\boldsymbol{T_{bar}^{initial}}$, ℃	$\boldsymbol{T^{final}}$, ℃	$\boldsymbol{C_{bar}}$, $\frac{J}{g \cdot ℃}$		**Error, %**
					Experimental	**Theoretical**	
Aluminum alloy							
Stainless steel							
Brass							
Copper							

16.2.2.3. Reference

A. Empty calorimeters specific heat.

$T_{cold} = 31°C$ $\quad$ $T_{hot} = 51°C$ $\quad$ $T_{final} = 40°C$

$\Delta T_{cold} = 9°C$ $\quad$ $\Delta T_{hot} = 11°C$

Specific heat of the water: $C_{water} = 4.18 \frac{J}{g \cdot °C}$

$Q_{cold} = m_{cold} \cdot C_{water} \cdot \Delta T_{cold} = 200g \cdot 4.18 \frac{J}{g \cdot °C} 9°C = 7524J \cdot$

$Q_{hot} = m_{hot} \cdot C_{water} \cdot \Delta T_{hot} = 200g \cdot 4.18 \frac{J}{g \cdot °C} 11°C = 9196J$

$Q_{cal} = -Q_{hot} - Q_{cold} = 1672J$

$m_{water} = m_{cold} + m_{hot} = 400g$

NOTE: Remember the calorimeter includes the $400\ g$ of water so we must include the heat capacity of this much water

NOTE: The temperature of the calorimeter will be taken as cold water temperature.

$\Delta T_{cold} = \Delta T_{cal} = 9°C$

$C_{cal} = \frac{Q_{cal}}{\Delta T} + C_{water} \cdot m_{water} = \frac{1672J}{9°C} + 4.18 \frac{J}{g \cdot °C} \cdot 400g = 1857.7 \frac{J}{°C}$

B. Materials specific heat

$C_{cal} = 1857.7 \frac{J}{°C}$

$Q_{cal} = -Q_{bar}$, it gives: $\quad C_{cal} \cdot \Delta T_{cal} = m_{bar} \cdot C_{bar} \cdot \Delta T_{bar}$

$C_{bar} = \frac{C_{cal} \cdot \left(T^{final} - T_{cal}^{initial}\right)}{m_{bar} \cdot (T^{final} - T_{bar}^{initial})}$

NOTE: We don't have to multiply by m_{cal}, because the mass of the calorimeter system is already included in the C_{cal} value.

Metal	$T_{cal}^{initial}$, °C	m_{bar}, g	$T_{bar}^{initial}$, °C	T^{final}, °C	C_{bar}, $\frac{J}{g \cdot °C}$		Error, %
					Experimental	**Theoretical**	
Aluminum alloy	31.3	49.48	86.6	32.7	0.975	0.896	8.81
Stainless steel	31.5	118.1	88.7	33.2	0.481	0.502	4.18
Brass	31.4	126	80.4	32.6	0.370	0.380	2.60
Copper	31.8	146.6	84.0	33.3	0.374	0.386	8.05

16.2.3. Equivalent of heat

16.2.3.1. Procedure

1. Make sure you have carried out *16.2.2.Part.A* and determined the specific heat of the calorimeter beforehand.
2. Assemble the equipment as illustrated in *Figure.1*.

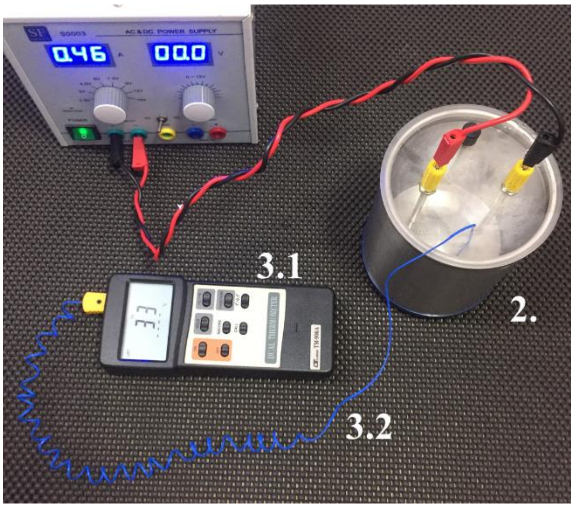


Figure.1 Experimental setup

3. Using a graduated cylinder, measure $400\ mL$ of distilled water. Pour the water into the calorimeter. Close the lid and dip a thermocouple (**3.2.**). Turn on the thermometer (**3.1.**) to measure the temperature of the water in the calorimeter (**2.**) until the temperature is steady. Calculate the average and record this temperature as $T_{cal}^{initial}$.

NOTE

When dipping the thermocouple tip into the water, please avoid touching the bottom or the heating wire. It must be measuring the water temperature not any metal surface.

4. Connect the DC/AC power supply to the calorimeter via patch cords.
5. Turn the power supply on, toggle to DC mode, and increase the voltage to 7V or lower.

NOTE:

It would be easier to observe the changes as lower voltage increases temperature slower than higher.

6. Measure the temperature every 1 or 2 minutes until the temperature rises around 50℃.

NOTE:

Swirl occasionally while heating up the calorimeter to distribute the heat as uniform as possible.

7. Calculate the equivalent of heat using the "Least square method" and compare with the theoretical values (See *16.2.3.4 Appendix*).

<u>Least square method:</u>

a. Calculate the deviation of the temperature at i temperature: $\Delta T = T_i - T_0$

b. Calculate the work and heat: $W = IVt$; $Q = C_{cal}(T_2 - T_1)$

NOTE: Remember to convert time unit to seconds as $1\,Joule$ equals to $1\,Watt * secounds$

c. Sum the W (Y variables) and Q (X variables) and then calculate the average values.

d. Calculate $(X - \overline{X})$; $(Y - \overline{Y})$; $(X - \overline{X})^2$; $(Y - \overline{Y})^2$ and $(X - \overline{X})(Y - \overline{Y})$.

e. Calculate sums of $(X - \overline{X})^2$, $(Y - \overline{Y})^2$ and $(X - \overline{X})(Y - \overline{Y})$ and note as m, p and n respectively.

f. Use following equation to obtain "Thermal expansion coefficient (α)":

$y = \alpha x + \beta$ Where: $\alpha = \frac{n}{m}$ and $\beta = \overline{Y} - \alpha\overline{X}$

g. Finally, the coefficient of determination will be calculated as follows:

$$R^2 = \left(\frac{\sum[(X-\overline{X})(Y-\overline{Y})]}{\sqrt{(X-\overline{X})^2(Y-\overline{Y})^2}}\right)^2$$

8. Plot the heat of the system as a function work done at each step to see whether the work is directly converted into the heat.

NOTE:

A calorie is defined as the amount of heat that raises the temperature of 1 gram of water by 1 degree Celsius. Contemporary SI units do not distinguish between heat energy and mechanical energy, so that heat is also measured in Joules. Therefore,α, the equivalent of heat, the ratio of work performed to the heat produced will not have any unit.

16.2.3.2. Results

Specific heat capacity of the system ($\boldsymbol{C_{system}} + \boldsymbol{C_{water}} = \boldsymbol{C_{cal}} =$ _____ $\frac{J}{g{\cdot}℃}$)

Initial temperature of the system: ($\boldsymbol{T_1} =$ _____ ℃)

Current ($\boldsymbol{I} =$ _____ A); Voltage ($\boldsymbol{V} =$ _____ V)

According to *Equation. (3)*, the equivalent of heat supposed to be calculated as follows:

$$\boldsymbol{\alpha = \frac{W}{Q} = \frac{IVt}{C_{cal}(T_2 - T_1)}}$$

To increase the accuracy of the calculation using the Least square method to find the best fit for this set of data, we use work (W) as a Y variables and heat (Q) as X variables.

	$\boldsymbol{t,\ min}$	$\boldsymbol{T_2}$, ℃	$\Delta\boldsymbol{T}$, ℃	$\boldsymbol{W, J}$	$\boldsymbol{Q, J}$	$(\boldsymbol{X} - \overline{X})$	$(\boldsymbol{Y} - \overline{Y})$	$(\boldsymbol{X} - \overline{X})^2$	$(\boldsymbol{Y} - \overline{Y})^2$	$(\boldsymbol{X} - \overline{X})(\boldsymbol{Y} - \overline{Y})$
Sum								$\boldsymbol{m}$=	$\boldsymbol{p}$=	$\boldsymbol{n}$=
Mean				$\overline{\boldsymbol{Y}}$=	$\overline{\boldsymbol{X}}$=					

Ideal equivalent of heat: α=1.00

The error of the experiment: $= \frac{|Theoretical\ value - Experimental\ value|}{Theoretical\ value} * 100\%$

16.2.3.3. Reference

Specific heat capacity of the system ($\boldsymbol{C_{cal}} = 1857.7 \frac{J}{℃}$)

Initial temperature of the system: ($\boldsymbol{T_1} = 31$ ℃)

Current ($\boldsymbol{I} = 2.56A$); Voltage ($\boldsymbol{V} = 7.3V$)

According to *Equation. (3)*, the equivalent of heat supposed to be calculated as follows:

$$\boldsymbol{\alpha = \frac{W}{Q} = \frac{IVt}{C_{cal}(T_2 - T_1)}} \ .$$

However, to increase accuracy of the calculation using the Least square method to find the best fit for this set of data, we use work (W) as Y variables and heat (Q) as X variables.

	Time, min	T_2,℃	ΔT,℃	$W, Joule$	$Q, Joule$	$(X-\overline{X})$	$(Y-\overline{Y})$	$(X-\overline{X})^2$	$(Y-\overline{Y})^2$	$(X-\overline{X})(Y-\overline{Y})$
	1	32.2	0.4	1121.28	743.08	-13784.134	-144645	190002350	2.092E+10	1993811025
	2	32.8	1	2242.56	1857.7	-12669.514	-143524	160516585	2.06E+10	1818380341
	3	33.6	1.8	3363.84	3343.86	-11183.354	-142403	125067407	2.028E+10	1592540923
	4	34.2	2.4	4485.12	4458.48	-10068.734	-141282	101379404	1.996E+10	1422526044
	5	34.9	3.1	5606.4	5758.87	-8768.344	-140160	76883857	1.964E+10	1228973199
	6	35.5	3.7	6727.68	6873.49	-7653.724	-139039	58579491	1.933E+10	1064165825
	7	36.1	4.3	7848.96	7988.11	-6539.104	-137918	42759881	1.902E+10	901858053
	8	36.8	5	8970.24	9288.5	-5238.714	-136796	27444124	1.871E+10	716637215.8
	9	37.5	5.7	10091.52	10588.89	-3938.324	-135675	15510396	1.841E+10	534332581.3
	10	38	6.2	11212.8	11517.74	-3009.474	-134554	9056933.8	1.81E+10	404936283.1
	11	38.6	6.8	12334.08	12632.36	-1894.854	-133433	3590471.7	1.78E+10	252835220
	12	39.2	7.4	13455.36	13746.98	-780.234	-132311	608765.09	1.751E+10	103233759.2
	13	39.8	8	14576.64	14861.6	334.386	-131190	111814	1.721E+10	-43868099.34
	14	40.5	8.7	15697.92	16161.99	1634.776	-130069	2672492.6	1.692E+10	-212633221.8
	15	40.9	9.1	16819.2	16905.07	2377.856	-128947	5654199.2	1.663E+10	-306618443.9
	16	41.6	9.8	17940.48	18205.46	3678.246	-127826	13529494	1.634E+10	-470176061.7
	17	42.1	10.3	19061.76	19134.31	4607.096	-126705	21225334	1.605E+10	-583741545.8
	18	42.6	10.8	20183.04	20063.16	5535.946	-125584	30646698	1.577E+10	-695224028.1
	19	43.2	11.4	21304.32	21177.78	6650.566	-124462	44230028	1.549E+10	-827744873.7
	20	43.7	11.9	22425.6	22106.63	7579.416	-123341	57447547	1.521E+10	-934853052
	21	44.3	12.5	23546.88	23221.25	8694.036	-122220	75586262	1.494E+10	-1062582993
	22	44.8	13	24668.16	24150.1	9622.886	-121098	92599935	1.466E+10	-1165316868
	23	45.3	13.5	25789.44	25078.95	10551.736	-119977	111339133	1.439E+10	-1265967740
	24	45.9	14.1	26910.72	26193.57	11666.356	-118856	136103862	1.413E+10	-1386615475
	25	46.4	14.6	28032	27122.42	12595.206	-117735	158639214	1.386E+10	-1482892044
SUM				**364416**	**363180.35**			**1.561E+09**	**4.319E+11**	**1595996022**
Mean				**14576.64**	**14527.214**					

$\alpha = \frac{n}{m} = \frac{1595996022}{1.561+09} = 1.022297376$ and;

$\beta = \overline{Y} - \alpha\overline{X} = 14576.64 - 1.022297376 * 14527.214 = -274.4927546$;

Where: α: is the "Equivalent of heat "

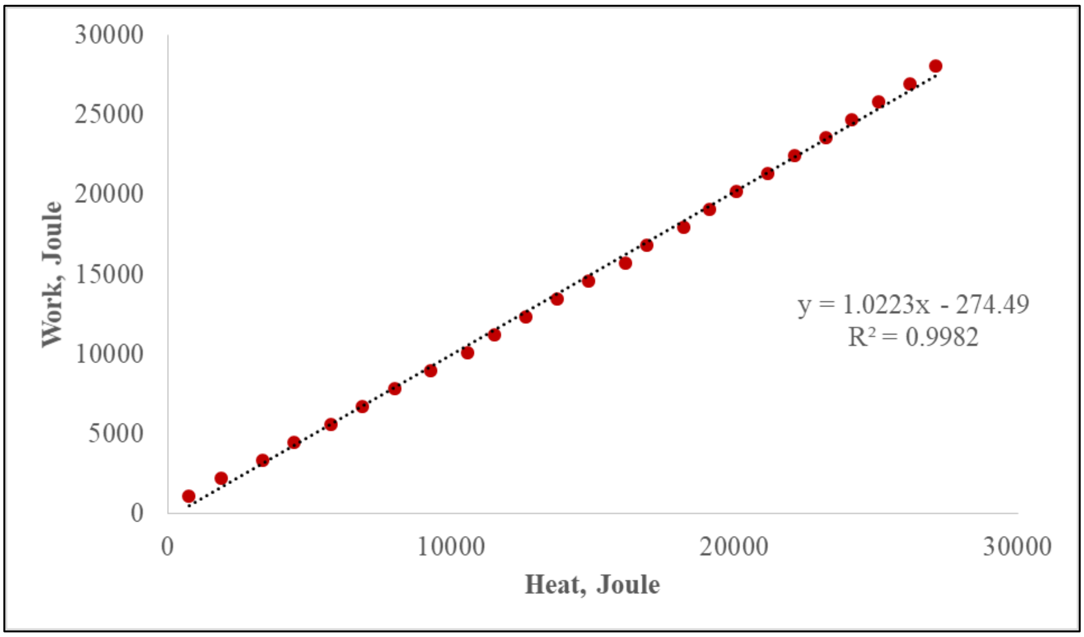
Finally, $y = 1.02x - 274.49$ and $R^2 = (\frac{n}{\sqrt{m*p}})^2 = 0.9982$

Ideal equivalent of heat: α=1.00

The error of the experiment: $= \frac{|Theoretical\ value - Experimental\ value|}{Theoretical\ value} * 100\% = 2.22\%$

NOTE: This error accounts for the heat dissipation of the system.

This graph shows a linear correlation between the heat of the system versus the work performed from outside, which assures the amount of heat produced is directly proportional to the amount of work done and is persistent with the First law of Thermodynamic.



16.2.3.4. Appendix

Name	Heat capacity $℃^{-1}$	Linear thermal expansion coefficient $\frac{J}{g \cdot ℃}$	Length of the rod mm	Mass of the bar g
Aluminum alloy (6061)[1]	$2.36 * 10^{-5}$	0.896	460	49.5
Stainless steel (304)[2]	$1.73 * 10^{-5}$	0.502	460	118.1
Brass (C3604)[3]	$2.05 * 10^{-5}$	0.380	460	126.0
Copper (C1100)[3]	$1.77 * 10^{-5}$	0.386	460	146.6

[1] Metals Handbook, Vol.2, Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International 10th edition, 1990.
[2] Engineering Properties of Steels, Philip D. Harvey, American Society for Metals, 1982.
[3] Copper Development Association.