1 Objective

We propose by...

Using a steam generator and a piece of and a block of ice, we propose that we can accurately measure the thermal conductivity of a piece of material to within 5% of the true value. Additionally, we propose that by electronically measuring the pressure and temperature of a volume of ice, we can experimentally prove the ideal gas law to within 5% accuracy.

2 Methods

2.1 Thermal Conductivity

By using measuring the cross-sectional area of the
ice, \( A \pm \Delta A \), in contact with a material of
contact with a material of thickness, \( h \pm \Delta h \), we
may estimate the surface area in contact with the
material

\[
A \pm \Delta A = \frac{\pi}{4} (d)^2 \pm \frac{\pi}{4} \Delta (d)^2
\]

Additionally, by measuring the mass of the ice collecting
cup \( m_1 \pm \Delta m_1 \) before and after an interval \( \Delta m \) of
a time interval \( t \pm \Delta t \), we can estimate the melting
rate

\[
\frac{\Delta m}{\Delta t} = \frac{\Delta m_1}{\Delta t} = \frac{m_1 - m_2}{t} \pm \frac{(m_1 + m_2)}{t} \Delta m
\]

From the measurement, we assume the ice is subject to heat
we may calculate thermal conductivity as

\[
\frac{\Delta m}{\Delta t} = \frac{c}{\Delta (T_m - T_e)} (\frac{1}{t} \frac{\Delta m}{\Delta t} + \frac{T_m + T_e}{h} + \frac{T_m + T_e}{A} + \frac{T_m + T_e}{(T_m - T_e)}
\]

2.2 Ideal Gas Law

By taking uncompressed sensor readings \( V_1', V_2', P_1', P_2' \)
and compressed sensor readings \( V_1, V_2, P_1, P_2 \),
we may estimate \( V_0 \) to account for pressure in the
tube

\[
V_0 \pm \Delta V_0 = \left( \frac{V_2 P_2 - V_1 P_1}{P_1 - P_2} \right) \left( \frac{\rho V_0}{P_1} + \frac{\rho V_1}{P_2} + \frac{\rho V_0}{T_0} \right)
\]

Then we may confirm the ideal gas law by calculating
the below and checking their equivalence

\[
\frac{P_0 V_1}{T_0} = \left( \frac{P_2}{P_0} \right) \frac{V_0}{T_0} + \frac{\rho V_0}{T_0}
\]

where

\[
V_0' \pm \Delta V_0' = \left( \frac{V_2' V_0}{V_1'} \right) \left( \frac{T_0'}{T_0} \right) \left( \frac{V_0}{V_1} \right)
\]
3.1 Error Derivations

3.1.1 Thermal Conductivity

Change in mass
\[ \Delta M \pm \Delta M = (M_2 \pm \Delta m_2) - (M_1 \pm \Delta m_1) \]
\[ = (M_2 - M_1) \pm (\Delta m_2 + \Delta m_1) \]
\[ \Delta m \pm \Delta m = (m_2 - m_1) \pm (\Delta m_2 + \Delta m_1) \]

Area
\[ A \pm \Delta A = \frac{(\Delta L)^2}{4} \pi \left( \frac{d \pm \Delta d}{2} \right)^2 \]
\[ = \pi \left( \frac{\Delta L}{4} \right)^2 \]
\[ = \pi \left( \frac{d}{2} \right)^2 \]
\[ = \pi \left( \frac{d^2}{4} \right) \]
\[ A \pm \Delta A = \pi \left( \frac{d^2}{4} \pm \frac{1}{2} \Delta d \right) \]

Melting radius
\[ R \pm \Delta R = \frac{\Delta M \pm \Delta M}{(t \pm \Delta t)} \]
\[ = \Delta M \left( \frac{t \pm \Delta t}{t \pm \Delta t} \right) \]
\[ = \Delta M \left( \frac{t \pm \Delta t}{t \pm \Delta t} \right) \]
\[ R \pm \Delta R = \Delta M \left( \frac{t \pm \Delta t}{t \pm \Delta t} \right) \]

Heat absorption
\[ Q \pm \Delta Q = \frac{\Delta M}{c} \left( \frac{t \pm \Delta t}{t \pm \Delta t} \right) \]
\[ = \frac{\Delta M}{c} \left( \frac{t \pm \Delta t}{t \pm \Delta t} \right) \]
\[ Q \pm \Delta Q = \frac{\Delta M}{c} \left( \frac{t \pm \Delta t}{t \pm \Delta t} \right) \]

Thermal conductivity
\[ K \pm \Delta K = \frac{(\Delta L)^2}{4} \pi \left( \frac{d \pm \Delta d}{2} \right)^2 \]
\[ = \left[ \frac{(\Delta L)^2}{4} \right] \left( \frac{d \pm \Delta d}{2} \right)^2 \]
\[ = \left[ \frac{(\Delta L)^2}{4} \right] \left( \frac{d \pm \Delta d}{2} \right)^2 \]
\[ = \left[ \frac{(\Delta L)^2}{4} \right] \left( \frac{d \pm \Delta d}{2} \right)^2 \]
\[ K \pm \Delta K = \frac{(\Delta L)^2}{4} \pi \left( \frac{d \pm \Delta d}{2} \right)^2 \]
\[ = \frac{(\Delta L)^2}{4} \pi \left( \frac{d \pm \Delta d}{2} \right)^2 \]
\[ K \pm \Delta K = \frac{(\Delta L)^2}{4} \pi \left( \frac{d \pm \Delta d}{2} \right)^2 \]
\[ K \pm \Delta K = \frac{(\Delta L)^2}{4} \pi \left( \frac{d \pm \Delta d}{2} \right)^2 \]
### Ideal Gas

**Volume Adjustment Value**

\[
\frac{V_1 + V_0}{V_2 + V_0} = \frac{P_2}{P_1}
\]

\[
V_1 P_1 + V_0 P_1 = P_2 V_2 + V_0 P_2
\]

\[
V_0 P_1 - V_0 P_2 = P_2 V_2 - V_1 P_1
\]

\[
V_0 (P_1 - P_2) = P_2 V_2 - V_1 P_1
\]

\[
V_0 = \left( \frac{P_2 V_2 - V_1 P_1}{P_1 - P_2} \right)
\]

\[
v_0 \pm \Delta v_0 = \left[ \left( \frac{P_2 \pm \Delta P_2}{P_1 \pm \Delta P_1} \right) \left( V_2 \pm \Delta V_2 \right) \right] / \left[ \left( P_1 \pm \Delta P_1 \right) \left( V_1 \pm \Delta V_1 \right) \right]
\]

\[
V_0 \pm \Delta V_0 = \left( \frac{P_2 V_2 - V_1 P_1}{P_1 - P_2} \right) \left( v_0 \pm \Delta v_0 \right)
\]

**Adjusted Volumes**

\[
v_1' + \Delta v_1' = (V_1 \pm \Delta V_1) \pm \left( \frac{v_0 \pm \Delta v_0}{P_1 \pm \Delta P_1} \right)
\]

\[
v_2' + \Delta v_2' = (V_2 \pm \Delta V_2) \pm \left( \frac{v_0 \pm \Delta v_0}{P_1 \pm \Delta P_1} \right)
\]

**Updated PT**

\[
\frac{(P_0 \pm \Delta P_0)(V_2 \pm \Delta V_2)}{(T_0 \pm \Delta T_0)} = (nR_0 \pm \Delta nR_0)
\]

\[
\frac{P_0 V_2'}{T_0} \left( 1 \pm \frac{T_0}{T_0} \right) = \left( \frac{nR_0}{P_0} \pm \Delta nR_0 \right)
\]

\[
\frac{P_0 V_1'}{T_0} \left( 1 \pm \frac{T_0}{P_0} \right) = nR_0 \pm \Delta nR_0
\]
### 3.2 Data for Thermal Conductivity

#### 3.2.1 Table 1

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Uncertainty (m)</th>
<th>Temperature of ice (K)</th>
<th>Uncertainty (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of material</td>
<td>0.0057</td>
<td>373.15</td>
<td>0.0001</td>
</tr>
<tr>
<td>Initial ice diam. (m)</td>
<td>0.0770</td>
<td>373.15</td>
<td>0.0001</td>
</tr>
<tr>
<td>Mass of empty cup (kg)</td>
<td>0.0077</td>
<td>Final ice diam. (m)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Mass of full cup (kg)</td>
<td>0.0190</td>
<td>Mass of empty cup (kg)</td>
<td>0.0016</td>
</tr>
<tr>
<td>Time (s)</td>
<td>350.97</td>
<td>Time (s)</td>
<td>418.79</td>
</tr>
</tbody>
</table>

Heat absorbed (J/l) 23.46 Uncertainty (J/l) 0.46

Thermal conductivity (W/mK) 0.27 Uncertainty (W/mK) 0.11

#### 3.2.2 Questions

How does thermal conductivity compare?

Our estimated value for thermal conductivity was 0.27 ± 0.01 (W/mK) and the true value of thermal conductivity for glass ranges from 0.72 to 0.86, indicating the percent error for our between our estimate is 64.51% ± 0.01%. 

Source of error:

In our experiment, the ice did not remain constantly frozen against the material permitting a layer of water to form between the ice and the glass, thus the heat was not transferred to the ice directly, but to the water first to the ice. Additionally, the point of contact cannot be assumed to be uniform. Heat losses the angle allows for a thermal gradient.

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Note: The calculations and errors seem to be done correctly, but the units and context of the final results could be clearer. The uncertainty in the measurement of time and mass should be noted, as well as the consistency of units throughout the calculations.
### 3.3 Ideal Gas

#### 3.3.1 Table

<table>
<thead>
<tr>
<th>Volume compressed (m$^3$)</th>
<th>0.000021</th>
<th>Volume uncompressed (m$^3$)</th>
<th>0.000001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty (m$^3$)</td>
<td>0.000040</td>
<td>Uncertainty (m$^3$)</td>
<td>0.000001</td>
</tr>
<tr>
<td>Pressure compressed (atm)</td>
<td>1.8345</td>
<td>Pressure uncompressed (atm)</td>
<td>1.0055</td>
</tr>
<tr>
<td>Uncertainty (atm)</td>
<td>0.0001</td>
<td>Uncertainty (atm)</td>
<td>0.0001</td>
</tr>
<tr>
<td>$V_0$ (m$^3$)</td>
<td>0.000022</td>
<td>$V_1$ (m$^3$)</td>
<td>0.000023</td>
</tr>
<tr>
<td>Uncertainty (m$^3$)</td>
<td>0.000001</td>
<td>Uncertainty (m$^3$)</td>
<td>0.000001</td>
</tr>
<tr>
<td>$P_3$ (atm)</td>
<td>1.0055</td>
<td>$V_2$ (m$^3$)</td>
<td>0.000042</td>
</tr>
<tr>
<td>Uncertainty (atm)</td>
<td>0.0001</td>
<td>Uncertainty (m$^3$)</td>
<td>0.000001</td>
</tr>
<tr>
<td>$T_3$ (K)</td>
<td>300.00</td>
<td>$n \cdot P_3$ (atm m$^3$/K)</td>
<td>0.0000014</td>
</tr>
<tr>
<td>Uncertainty (K)</td>
<td>0.01</td>
<td>Uncertainty (atm m$^3$/K)</td>
<td>0.0000003</td>
</tr>
<tr>
<td>$P_4$ (atm)</td>
<td>1.9647</td>
<td>$n \cdot P_4$ (atm m$^3$/K)</td>
<td>0.0000014</td>
</tr>
<tr>
<td>Uncertainty (atm)</td>
<td>0.0001</td>
<td>Uncertainty (atm m$^3$/K)</td>
<td>0.0000006</td>
</tr>
<tr>
<td>$T_4$ (K)</td>
<td>314.06</td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td>Uncertainty (K)</td>
<td>0.01</td>
<td></td>
<td>0.05</td>
</tr>
</tbody>
</table>

#### 3.3.2 Questions

**Temperature** $T$ is approximately same?

The temperature was constant because the ideal gas law $PV=nRT$ when pressure is increased, volume drops to keep pressure the same. Likewise, if volume is increased, pressure drops to accommodate.

Ratios $V_c/V_0$ and $P_c/P_0$,

we obtained values as $0.525 \pm 0.036$ and $0.549 \pm 0.003$ for $V_c/V_0$ and $P_c/P_0$ respectively. They are equal within error.

Why doesn't plunger return?

The plunger doesn't return because of leakage in the tube. It's a loss point for pressure which cannot be converted into work to increase the volume when the plunger is released.

*Primarily due to heat transfer. T is a constant, then $P$ is a constant, but not reversibly.*
Why must plunger move fast for \( p_0 V_0 \frac{1}{T_0} \) and \( p_0 V_1 \frac{1}{T_1} \) to be equal?

If we were to slowly press the plunger down, we would allow the heat to dissipate and thus temperature would not change. By compressing the plunger quickly, we can force \( \Delta E = 0 \) for \( \Delta E = Q - W \leq 0 \).

Why is there a dramatic change in pressure?

Once we quickly compress the volume, we induce a temporary disequilibrium in the pressure that we call the gas, thus for we see the pressure spike.

What happens when plunger is released?

When the plunger is released the system does work to expand the volume. The pressure drops and since the temperature drops, but stabilizes as the system reaches equilibrium.

3.34 Adiabatic Demo

In an adiabatic process the volume rapidly decreases and thus since the system cannot rapidly reach equilibrium by allowing heat into or removed by the drop in pressure to dissipate so the temperature of the gas rises to a point of combustion.

4 Conclusions

We initially hypothesized we could accurately estimate the thermal conductivity of a material using the melt rate of ice within 5% of the value. We obtained a conductivity of 0.24 ± 0.01 W/km and 0.92 W/km for the true value from Table 1. This results in an error of 1.1% error, thus we can conclude that we can accurately estimate the thermal property of a material using the melt rate of ice. We additionally hypothesized we could accurately prove the ideal gas law, we measured volumes of 1.446 ± 0.01 L air/m³ and 1.446 ± 0.01 L/m³ resulting in a 0% error. However, the uncertainties do not fall within each other, thus far we can say we successfully achieved a 5% error but cannot conclude the ideal gas law holds within error.
Suggestions

1. Use a spring fixture to hold the ice onto the surface.

2. Create a sealed channel such that there is no loss in water flow.

3. Use a shouldn't compression to ensure no heat is lost when compression occurs for ideal gas laws experiment.

But then you are using adiabatic laws. Cannot use \( \frac{PV}{T} = \text{const.} \)
## Measurement 2: Ideal Gas Law

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Abs U (m^3)</th>
<th>Rel U</th>
</tr>
</thead>
<tbody>
<tr>
<td>V Compressed (m^3)</td>
<td>0.000021</td>
<td>0.000001</td>
<td>0.0476</td>
</tr>
<tr>
<td>V Uncompressed (m^3)</td>
<td>0.000040</td>
<td>0.000001</td>
<td>0.0250</td>
</tr>
<tr>
<td>P Compressed (atm)</td>
<td>1.8348</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>P Uncompressed (atm)</td>
<td>1.0055</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>V_0 (m^3)</td>
<td>0.0000020</td>
<td>0.000001</td>
<td>0.036</td>
</tr>
<tr>
<td>P3 (atm)</td>
<td>1.0055</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>P4 (atm)</td>
<td>1.9647</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>V1' (m^3)</td>
<td>0.000023</td>
<td>0.000001</td>
<td>0.0466</td>
</tr>
<tr>
<td>V2' (m^3)</td>
<td>0.000042</td>
<td>0.000001</td>
<td>0.0256</td>
</tr>
<tr>
<td>[ P3 \times V2' / T3 ] (atm*m^3/K)</td>
<td>0.0000001</td>
<td>0.0000000</td>
<td>0.0257</td>
</tr>
<tr>
<td>[ P4 \times V1' / T4 ] (atm*m^3/K)</td>
<td>0.0000001</td>
<td>0.0000000</td>
<td>0.04670788</td>
</tr>
</tbody>
</table>

### Calculations

- 1ml * right = m^3
- Pa * right = atm
- V_C/V_U 0.53
- P_U/P_C 0.55
- Percent Error 0.0223
- Abs U 0.0708
- Rel U 3.1772

---

### Computer 1

- T3 (K) 300.00
- T4 (K) 314.08
- Abs U (K) 0.01
- Rel U 0.00
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Abs U (m)</th>
<th>Rel U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness 1 (m)</td>
<td>0.0057</td>
<td>0.0175</td>
</tr>
<tr>
<td>Temperature ice (K)</td>
<td>273.15</td>
<td></td>
</tr>
<tr>
<td>Initial diameter 1 (m)</td>
<td>0.00</td>
<td>0.0013</td>
</tr>
<tr>
<td>Mass cup 2 empty (kg)</td>
<td>0.0077</td>
<td>0.0130</td>
</tr>
<tr>
<td>Mass cup 2 full (kg)</td>
<td>0.0190</td>
<td></td>
</tr>
<tr>
<td>Time_1 (s)</td>
<td>350.97</td>
<td>0.01</td>
</tr>
<tr>
<td>Mass cup 3 empty (kg)</td>
<td>0.0078</td>
<td>0.0128</td>
</tr>
<tr>
<td>Mass cup 3 full (kg)</td>
<td>0.0507</td>
<td></td>
</tr>
<tr>
<td>Time_2 (s)</td>
<td>418.78</td>
<td>0.01</td>
</tr>
<tr>
<td>Melt rate heat (kg/s)</td>
<td>0.0060</td>
<td>0.0047</td>
</tr>
<tr>
<td>Melt rate room (kg/s)</td>
<td>0.0007</td>
<td></td>
</tr>
<tr>
<td>Heat absorbed (J/s)</td>
<td>23.46</td>
<td>0.35</td>
</tr>
<tr>
<td>Average diameter (m)</td>
<td>0.0781</td>
<td>0.0013</td>
</tr>
<tr>
<td>Average area (m^2)</td>
<td>0.0048</td>
<td>0.0051</td>
</tr>
<tr>
<td>Thermal K (1/(Kms))</td>
<td>0.28</td>
<td>0.04</td>
</tr>
<tr>
<td>True K (1/(Kms))</td>
<td>0.72</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Notes:**
- Mass difference_2 (kg): 0.0113
- Abs U (kg): 0.0002
- Rel U: 0.0177
- Mass difference_3 (kg): 0.0429
- Abs U (kg): 0.0002
- Rel U: 0.0047

**Computer 1**

If you need more digits, show it, don't put 0.
Objective: The purpose of this lab is to determine how close the thermal conductivity constant for a sample material is experimentally to its accepted value, as well as applying the ideal gas law to observe quantitative and qualitative changes in isochoric and adiabatic environments.

Procedure: Check steam generator to make sure it is 1/2-3/4 full. Set dial to HIGH and powerswitch to ON. Select a sample material and use calipers to measure its thickness h. Slide under clamps and lock in place. Take block of ice and run under H2O for 5-10 sec. Ice should crack and loosen. Place on 1st sample material + plate paper car below channel. Let sit for few min, begin timer. Collect ice for 6-10 min. Attach ends of plastic tube to port of S. Connect longer tube to lower port, place open end in well which captures water from steam cooled. Measure new mass of cup (M0). Replace cup after several min with another empty cup and repeat (t, M1, M2). Finally measure ice block diameter dA.

3.2: Push plunger down until it stops @ bottom. Record this volume as V1. (≈ 20 cc). Lift plunger until @ 40 cc. This is V2. Attach pressure connector and make sure to connector is plugged in. Open "Ideal Gas Law". Data. Hit start, quickly and fully compress plunger. Hold meter until T* and P have stabilized (30-45 sec). Before plunger lets go speed back on. Hit stop. Highlight early P, cell (P1, P2, highlight just where piston is released, call it P3), Highlight region on T* graph @ beginning. Call T3 and P3. Highlight when to is max, record as T4, P4.

3.3: Remove piston from compression ignition, return ring seal of tissue into lower end of glass tube. Remove loading rod, reinset piston. Hold tube securely with hand. Snap knob of piston, ignite paper.

Equations:

1) \( \Delta E = Q - W \)
2) \( Q = \int_{T1}^{T2} C_v \, dT \)
3) \( C_v = \frac{3}{2} R \) (for diatomic)
4) \( Q = m \cdot C_v \cdot \Delta T \)
5) \( A = \pi \left( \frac{d}{2} \right)^2 \)
6) \( P_1 V_1 = n \cdot R \cdot T_1 \cdot P_2 V_2 \) (\( \frac{P_0}{V_0} = \frac{V_1}{V_2} \))

Data:

| Material | h | dp | 5.1 ± 0.1 cm | 5.0 ± 0.1 cm | 7.6 ± 0.2 cm | 8.4 ± 0.1 cm | 9.3 ± 0.2 cm | 10.2 ± 0.1 cm | 10.5 ± 0.1 cm | 10.5 ± 0.1 cm | 7.3 ± 0.2 cm | 8.4 ± 0.1 cm | 9.3 ± 0.2 cm | 10.2 ± 0.1 cm | 10.5 ± 0.1 cm | 7.3 ± 0.2 cm | 8.4 ± 0.1 cm | 9.3 ± 0.2 cm | 10.2 ± 0.1 cm | 10.5 ± 0.1 cm |
|----------|---|----|---------------|---------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|
| h 1 m | dp | 5.1 ± 0.1 cm | 5.0 ± 0.1 cm | 7.6 ± 0.2 cm | 8.4 ± 0.1 cm | 9.3 ± 0.2 cm | 10.2 ± 0.1 cm | 10.5 ± 0.1 cm | 7.3 ± 0.2 cm | 8.4 ± 0.1 cm | 9.3 ± 0.2 cm | 10.2 ± 0.1 cm | 10.5 ± 0.1 cm |

3.2

21.0 ± 1 mL = V1

V1 = 40.0 ± 1 mL
P0 = 101.9 ± 1 kPa
P1 = 177 ± 1 kPa
P2 = 101.9 ± 1 kPa
P3 = 101.9 ± 1 kPa
P4 = 101.9 ± 1 kPa

The temperatures at which the sample is compressed in PV = NkT, you are only changing PV; N x stays the same. Since PV = NkT, Temperature will not change. This relates to B.1 because in B.1, you are finding k constant while varying other factors in PV = NkT. The values in the PV/V and P/V are not equal. They differ by 342.2 kPa/mL.
d) The plunger does not return to its original volume because of the force of gravity pushing down on the plunger's force pushing back up.

\[ V = \frac{P_2}{P_1} \]

\[ V = \frac{21(\pm 0.05) + V_0}{40(\pm 0.02) + V_0} = \frac{(101.9)(\pm 0.01)}{(177.5)(\pm 0.006) V_0} \]

\[ = \frac{(101.9)(\pm 0.01)(40)(\pm 0.02) + ((101.9)(\pm 0.01) V_0)}{(177.5)(\pm 0.006) V_0} \]

\[ = \frac{333.8(\pm 0.005) + 177.8(\pm 0.006) V_0}{75.9(\pm 0.007)(V_0)^2} \]

\[ V_0 = 41.076(\pm 0.003) + 101.9(\pm 0.001) V_0 \]

\[ V_0 = 342.2(\pm 0.006) \]

\[ V_0 = 4.51(\pm 0) \text{ mL} \]

b) \[ P_1 = 148.7(\pm 0.1) \text{ kPa} \]

\[ T_1 = 41.6(\pm 1.1) \text{ ºC} \]

\[ (101.9)(\pm 0.01) \]

\[ P_2 = \frac{P_1 V_0}{T_1} = \frac{P_1 (V_1 + V_0)}{T_1} = \frac{101.9(\pm 0.1)(44.50656)(1\pm 0.016)}{42.6(1\pm 0.002347)} = \frac{453.545(\pm 0.0186)}{75.9(\pm 0.007)} \]

\[ = 60.357(\pm 0.221) \text{ kPa} \]

\[ = 1614(\pm 4) \text{ kPa} \]

\[ P_4 V_0 = \frac{P_4 (V_1 + V_0)}{T_4} = \frac{1614(\pm 4)(1\pm 0.0296)(25.50656)(1\pm 0.005)}{42.6(1\pm 0.002347)} = \frac{5068.59(\pm 0.211)}{42.6(1\pm 0.002347)} \]

\[ = 118.98(\pm 0.02497) \]

\[ = 119.0(\pm 2.8) \text{ kPa} \text{ mL} \]

c) You compress quickly to not lose energy due to heat.

There is an increase in pressure to account for PV = kT. Because the T stays relatively the same, and N and R remain unchanged, the whole right side of the Eq is a constant. If you decrease V, you must compensate with increasing the P value.

Energy lost due to work: \(-0.5\text{ J}\)

\[ A = \pi \left(\frac{7.25(\pm 0.027619)}{2}\right)^2 = \pi \left(5.05625 \text{ cm}^2 \pm 0.005323\right) = 41.822 \text{ cm}^2 \]

\[ = 41.3\pm 0.3 \text{ cm}^2 \]

\[ \text{a) } \rho = \frac{m}{V} = \frac{59.9(\pm 0.003333)}{10(\pm 0.1)} = 5.99(\pm 0.089) \text{ g/min} \]

\[ \text{b) } \rho = \frac{5.1(\pm 0.23539412)}{10(\pm 0.1)} = 5.5(\pm 0.03352741) = 5.5(\pm 0.3352741) \text{ g/min} \]

\[ \text{c) } Q = \frac{6.5(\pm 0.04686831) \times 3.342}{1716.76(\pm 0.04686831) \times 1716.76} = 5.14 \text{ cm}^3 \text{ g/min} \]

\[ Q = \frac{6.5(\pm 0.04686831) \times 3.342}{1716.76(\pm 0.04686831) \times 1716.76} = 5.14 \text{ cm}^3 \text{ g/min} \]

\[ Q = \frac{(1716.76)(\pm 0.04686831)(10)(\pm 0.1)}{1716.76(\pm 0.04686831)(10)(\pm 0.1)} = 1716.76 \text{ cm}^3 \text{ g/min} \]

\[ = 1716.76 \pm 0.9763 \text{ g/min} \]
If our material was glass, we were off by .24. This error could be due to eyeballing the times when collecting water in the cup, inaccuracy in measuring the water in the cup, and inaccuracy in the device. There all could have caused our value to be smaller than expected. Our value falls in to the "sheet rock" set of values.

Conclusion: In this experiment, we did not get the value expected for the glass material. We were off by .24, and got k = 0.72 ± 0.86 Watt/m·K instead off k = 0.72 ± 0.86 Watt/m·K. This could be due to a number of factors, including mismeasuring the water in both cups, eyeballing the times where we could have more or less water in the cups depending when we ended the times. In 3.2, we realized that by changing certain values in P=VNT, our variable that we were tracking could be held constant or increase depending on the other variables. Errors in this could be due to the program that we ran this on, as well as losing heat in the system.

\[
k = \frac{\text{Gh}}{4(T_{\text{hot}} - T_{\text{cold}}) t} = \frac{(7167.6 \pm 0.62(6331.5)(3.54)(1 \pm 0.16979)}{100 (10) (1.01) (41.3) (1 \pm 0.055 69)}
\]

\[
= \frac{10.12834 (2) 23635312}{10.41724}
\]

\[
= 1248251429 (1 \pm 13950393) = 25 \pm 0.3 \text{ J/cm·K·min}
\]

\[
\text{Watt} \rightarrow \text{m·K} \rightarrow \text{cm·K·min}
\]

\[
\text{sec·m·K} \rightarrow \text{min}
\]

\[
= 20.15 \pm 0.93 \text{ W/cm·K·min}
\]

\[
k = 25 \pm 0.3 \frac{J}{\text{cm·K·min}} \times \frac{100 \text{ cm}}{m} \times \frac{1 \text{ min}}{60 \text{ sec}} = 41666667 (1 \pm 13950393)
\]

\[
= 41666667 \pm 10 \text{ Watt/m·K}
\]

### 3.3

3rd part: \( T_2 = T_1 \left( \frac{V_1}{V_2} \right)^{\frac{1}{3}} \)

a) Because of this law, \( V_2 \) decreases through compression and \( T_2 \) increases to the point where it is hot enough to light up the tissue.

b) Compressing the plunger quickly is essential because you lose heat when you compress it slowly. When you lose heat, the \( T_2 \) does not change so the expected value and the tissue would not light up.
Objective: The purpose of this lab is to experimentally test 3 concepts of thermodynamics. These are verifying the ideal gas law, testing thermal conductivity, and applying simple thermal processes and see how they affect an ideal gas. By the end of the lab, we should have an accurately calculated value for k.

Method: This experiment is split into two parts.

3.1 We will begin by experimentally testing the ideal gas law and find the value for k. In order to do this we will use a heating apparatus and a thermal conductivity apparatus. By heating and melting an ice cube on a plate of known thickness and for a known amount of time we can use the formula

$$ K = \frac{mL}{A(t_final - t_initial)} $$

where L is the latent heat of fusion, m is the mass of the ice cube, A is the area of the plate, t_final is the final temperature, and t_initial is the initial temperature. By measuring the rate that the water increases, we can determine the temperature change of the water. Except for the cooling curves, we get all known values except k allowing us to calculate this.

3.2 Here we are testing the ideal gas law. By using a plunger hooked up to a computer we can measure volume and pressure and see how temperature changes. If we perform different tasks on the gas we can see how the ideal gas law holds. Using

$$ PV_1 = Nbt \quad \text{or} \quad \frac{V_1}{V_2} = \frac{P_1}{P_2} $$

we can quantify these changes.
Data Analysis

3.11

a) \[ R_1 = \frac{\text{m}}{t_1}, \quad R = R_1 - R_0 = 1.202 \times 10^{-4} \text{ kg/s} \] (See table)

b) We used \[ Q/4 = RL = (1.202 \times 10^{-4} \text{ kg/s}) (334000) \]
   We did total calculation in excel. See chanel. \[ \psi/kg \]

c) \[ A = \pi \left( \frac{\text{d}_{\text{ave}}}{2} \right)^2 = 4.66 \times 10^{-3} \text{ m}^2 \]

d) \[ T_{\text{hot}} = 3733 \text{ K} \quad T_{\text{cold}} = 273 \text{ K} \]

e) \[ K = 4.74 \times 10^{-1} \text{ W/m.K} + (5.6 \times 10^{-2}) \text{ W/m.K} \]

f) For error propagation see table for each individual error.

The accepted value range for glass is 0.42-0.6 W/m.K. Our value did not fall in the range of this, but we suspect this is natural as a lower value indicates conditions were not perfect which was true.

G) The largest source of error I believe was the machine dripping large amounts of water. The water indicates heat inside the conductivity chamber was escaping and thus the temperature inside was not 100\(^\circ\)C or 373K. If our \( T_{\text{hot}} \) was lower than expected, then in our equation:

\[ K = \frac{\text{m}Lh}{A(T_{\text{hot}} - T_{\text{cold}})} \]

then \( Lh / A \text{ would give us a higher } k \) perhaps something closer to the expected range.
3. Data analysis (cont.)

3.2 Ideal gas law

Part 1: Constant $T$

a) See Table 3, section 1, $P_2$.

b) See Table 3, section 1, $P_2$.

c) So this is because $PV = T$. So that means $V$ is the same then $P$ fluctuates relative to $V$. $T$ is the same.

$$\frac{V_1}{V_2} = \frac{P_2}{P_1} = 5.56 \times 10^{-1} \quad * \quad V_0 = 2.82 \pm 1.0 \times 10^{-1}$$

They aren't equal because $V_1$ and $V_2$ don't take into account for $V_0$, so when we adjust we get the value marked by $*$. 

d) It doesn't return because of section in the plunger which holds it in place.

Part 2: Varying $T$

a) See section 1 of Table 3.

b) See section 1 of Table 3.

c) They aren't equal because $P_2$ and $T_2$ are taken when we see temperature increase at an unexpected rate. This demonstrates a limit to the ideal gas law.

Quickly compressing it is essential because we don't want heat to dissipate into the environment. There is a dramatic increase in $P$ to account for the dramatic increase in $T$.

d) When the plunger is released, the temp decreases because $V$ increases creating more intermolecular collisions and thus less heat. 0.5 does work, small $V$, less $E$, smaller $T$. 
3.3) a) The air heats up as the air in the plunger is compressed. The temperature is so great that the paper combusts. Why increased?

b) If you did this slowly then you would lose heat energy to the environment and the plunger wouldn’t heat up. The temperature inside the plunger would not be high enough.

Conclusion: Overall this experiment is very effective at demonstrating the properties of thermodynamics. For 3.1, unfortunately our value of k was not in the accepted range and this was expected due to the condition of the apparatus. If we could insulate the conductivity better then we would be able to achieve a more constant internal temp and thus get a better value for k. Because we would have a more constant rate of melting.
### Table 3: Experiment 3.2 Ideal Gas Law

<table>
<thead>
<tr>
<th></th>
<th>V1 (cc)</th>
<th>V2 (cc)</th>
<th>P1 (kPa)</th>
<th>P2 (kPa)</th>
<th>P3 (kPa)</th>
<th>P4 (kPa)</th>
<th>T3 (°C)</th>
<th>T4 (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>2.10E+01</td>
<td>4.00E+01</td>
<td>1.84E+02</td>
<td>1.03E+02</td>
<td>1.03E+02</td>
<td>2.02E+02</td>
<td>2.81E+01</td>
<td>4.10E+01</td>
</tr>
<tr>
<td>Absolute Error</td>
<td>5.0E-01</td>
<td>5.0E-01</td>
<td>1.0E-02</td>
<td>1.0E-02</td>
<td>1.0E-02</td>
<td>1.0E-02</td>
<td>1.0E-02</td>
<td>1.0E-02</td>
</tr>
<tr>
<td>Relative Error</td>
<td>2.38E-02</td>
<td>1.25E-02</td>
<td>5.43E-05</td>
<td>9.76E-05</td>
<td>9.71E-05</td>
<td>4.95E-05</td>
<td>3.56E-04</td>
<td>2.44E-04</td>
</tr>
</tbody>
</table>

### Section 2

<table>
<thead>
<tr>
<th></th>
<th>V0 (cc)</th>
<th>V1' (cc)</th>
<th>V2'(cc)</th>
<th>V1'/V2'</th>
<th>P2/P1</th>
<th>P3V2'/T3</th>
<th>P4V1'/T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>2.82E+00</td>
<td>2.38E+01</td>
<td>4.28E+01</td>
<td>5.56E-01</td>
<td>5.56E-01</td>
<td>1.57E+02</td>
<td>1.17E+02</td>
</tr>
<tr>
<td>Absolute Error</td>
<td>1.0E-01</td>
<td>6.0E-01</td>
<td>6.0E-01</td>
<td>2.2E-02</td>
<td>8.4E-05</td>
<td>2.3E+00</td>
<td>3.0E+00</td>
</tr>
<tr>
<td>Relative Error</td>
<td>3.63E-02</td>
<td>2.53E-02</td>
<td>1.41E-02</td>
<td>3.94E-02</td>
<td>1.52E-04</td>
<td>1.45E-02</td>
<td>2.56E-02</td>
</tr>
</tbody>
</table>

Use $K$ instead of $cc$ in calculations.

Computer 3

**match digits**: 0.5