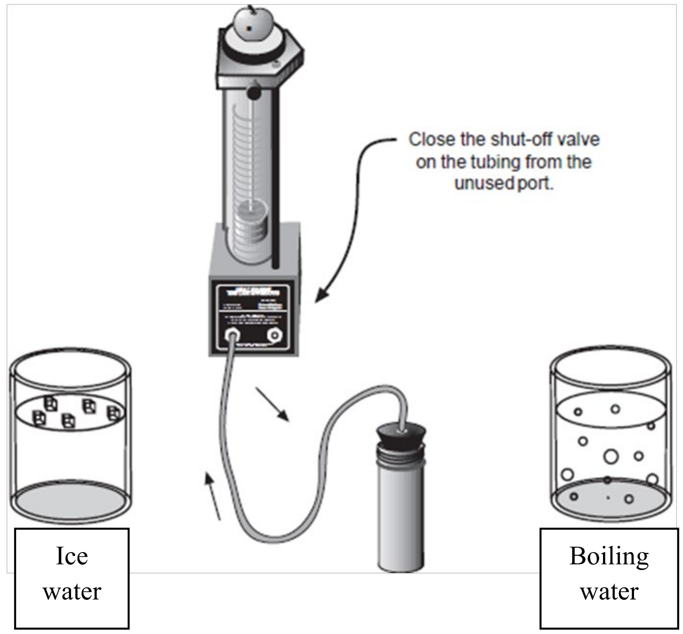
Mass Lifter/Heat Engine

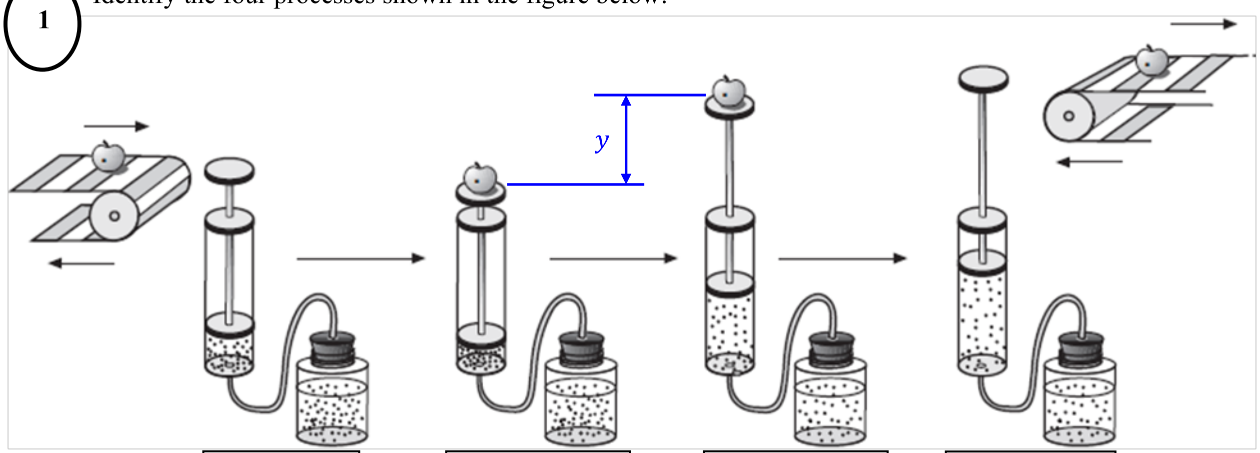
Apparatus: Heat Engine/Gas Law apparatus, digital calipers, 1 Pyrex beaker (at least 500 mL) per group, slotted masses, steam generators, ice (enough for 8 ice water baths in the beakers)

Goal: Verify area enclosed by a cycle on a PV-diagram matches net work done for a real-life process.

Instructions:
At right is a figure showing the apparatus. Practice making the piston go up and down by placing it in the ice water and the boiling water. Do this both with 150 g of weight on the piston without the 150 g.
Ensure sure the piston never touches the top or bottom of the cylinder before trying to take data.



1 Identify the four processes shown in the figure below:



A	**B**	**C**	**D**
no mass, cold gas	with mass, cold gas	with mass, hot gas	no mass, hot gas

A → B = ______________________________ **B → C** = ______________________________

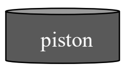
C → D = ______________________________ **D → A** = ______________________________

2 Draw a free-body of the piston. Use this free-body diagram to determine an algebraic expression for pressure inside the piston in terms of piston mass, piston diameter, atmospheric pressure P_0, and g.
Hint: $F_{\substack{air\ inside\\pushing\ upwards}} = P_{\substack{inside\\piston}} \times Area_{piston}$.

FBD

Force Equation

Solve for $P_{\substack{inside\\piston}}$



3 Use your algebraic result to tabulate pressure *inside the cylinder* for two cases.
Notice you can find important measurements on the apparatus (see figure at right).
Pay close attention to units and answer in units of kPa!
Even though it does not follow sig fig rules, keep <u>six</u> sig figs on these results.

$P_{\substack{piston\\only}}$ (kPa)	$P_{\substack{piston\\+150\ g}}$ (kPa)

mass & diameter info

4 Determine an algebraic expression for total volume of air inside your system as a function of piston height.
WATCH OUT! You must account for the air inside the can and the air beneath the piston.
Assume any volume lost due to the stopper in the can is offset by the volume of tubing.
Assume can diameter & height are d_1 & h_1 respectively.
Assume piston diameter & height are d_2 & h_2 respectively.

5

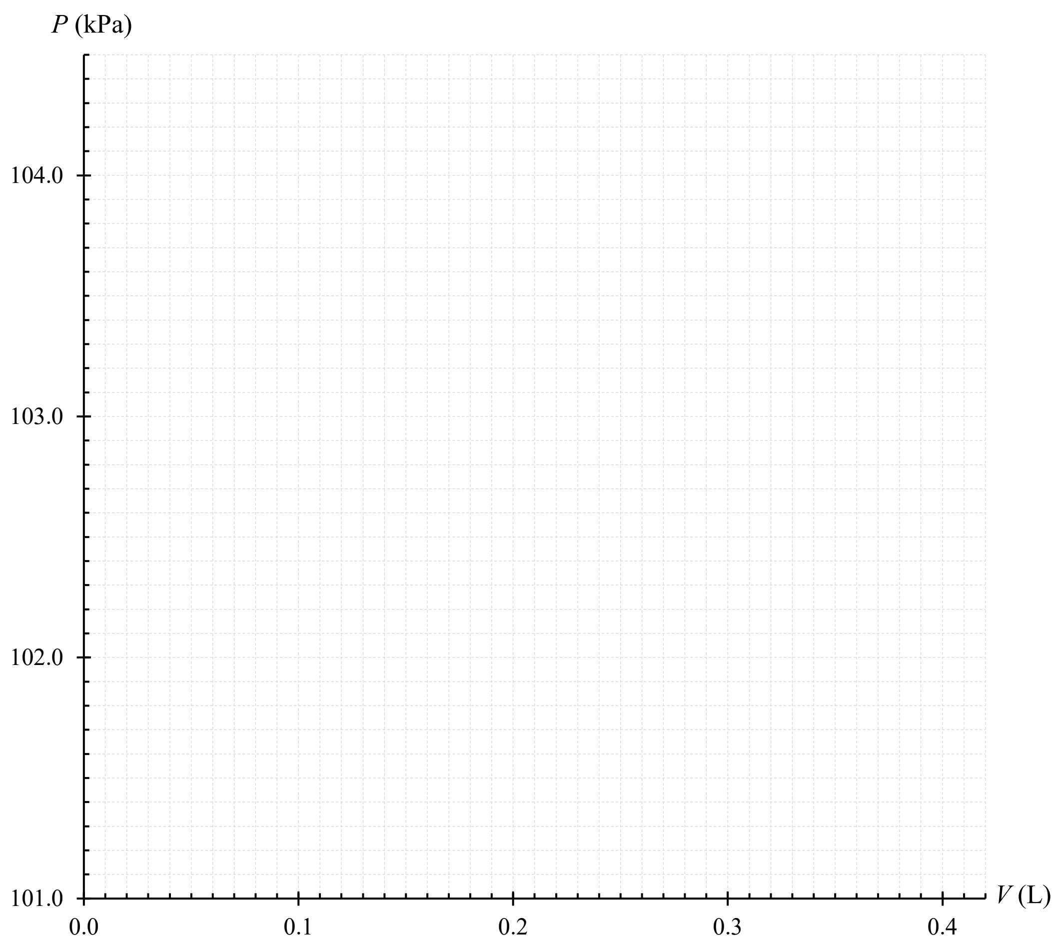
Take data for one complete cycle of the heat engine.
Notice you'll have to use some unit conversions to tabulate in the requested units.

Stage	***h*** **(mm)** 3 sig figs	P_{inside} **(kPa)** 6 sig figs	***V*** **(L)** 3 sig figs
A			
B			
C			
D			
A			

6

Sketch the PV diagram for the entire cycle on the plot below. On this plot, show the following:

- Label points **A**, **B**, **C**, and **D** and include an arrow for each process direction.
- **Show a calculation estimating the area enclosed for the entire cycle.**
  Note: area enclosed is *net* work by the gas for the cycle. Recall 1 kPa · 1 L = 1 J.
- Recall work done by the gas is positive for a clockwise cycle.



7

The net effect of the entire cycle is to lift the additional mass of $15\underline{0}$ g distance y. Determine the work required to lift $15\underline{0}$ g distance y. Consult the figure at the bottom of page 1 of this handout to help you determine a numerical value of y. Show your calculation here. It may help to read question 8 before computing.

8

Compare work required to lift the $15\underline{0}$ g mass (from step 7) to area enclosed on the PV-diagram (step 6). Include a % difference. I have to pick one result as the theory. Assume work obtained from step 6 is the theory result. Remember to round error calculations (such as percent difference) to one sig fig. Exception: use 2 sig figs if the first digit is 1.

9

Check if the process from **A → B** is accurately modeled as *adiabatic*. To do this, do the following:

- Assume your experimental values $P_A, V_A, \& P_B$ are givens.
- Use the adiabatic condition ($P_A V_A^\gamma = P_B V_B^\gamma$) to calculate $V_{B\,th}$.
- Assume $\gamma_{air} \approx 1.4$ for our temperature range.
- Compare $V_{B\,exp}$ (from measurements of piston height) to $V_{B\,th}$ with a percent difference.

10

Check if the process from **A → B** is accurately modeled as isothermal. To do this, do the following:

- Assume your experimental values $P_A, V_A, \& P_B$ are givens.
- Use the ideal gas law and a ratio to determine $V_{B\,th}$.

$$\frac{P_A V_A}{P_B V_B} = \frac{n_A R T_A}{n_B R T_B}$$

- Think: which parameters cancel out is we are assuming an isothermal process with no gas leaks?
- Compare $V_{B\,exp}$ (from measurements of piston height) to $V_{B\,th}$ with a percent difference.

Regardless of your results in steps 9 & 10, assume processes **A → B** & **C → D** are adiabatic when completing the chart on the next page. It is good exam practice since adiabatic processes are *slightly* tricker than isothermal processes. Also, last year several students got better results ignoring the heat added in processes **A → B** & **C → D** (by assuming they are adiabatic) compared to ignoring the change in internal energy for those processes (by assuming they were isothermal).

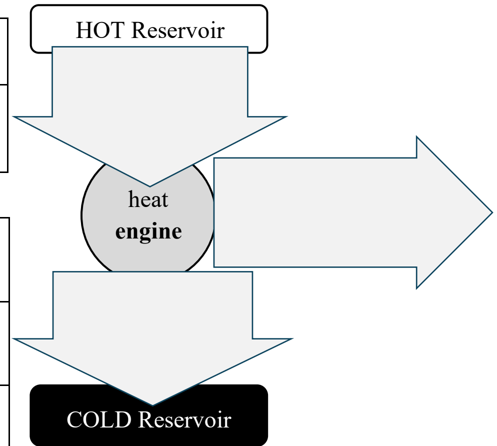
11

Complete the charts & engine diagram shown below. Show work (use an extra page if necessary). No lined paper! To determine power, assume 1 cycle can be completed in about 30 seconds. Recall the first law: $\Delta E_{int} = Q_{in} - W_{by}$. For temps: think about temperature during phase change…

T_A (K)	T_B (K)	T_C (K)	T_D (K)	f

Keep 4 sig figs but expect errors in the 1st or 2nd sig fig (A→ B & C→D not truly adiabatic).

	Name	Q_{in} (J)	$W_{by\ gas}$ (J)	ΔE_{int} (J)
A → B	`adiabatic`			
B → C				
C → D	`adiabatic`			
D → A				
For the Entire Cycle				



Efficiency $= \eta =$

Power Output $= \mathcal{P} =$

A closing note from Pasco (the company who makes this equipment):

The Incredible Mass Lifter Engine Is Not So Simple

Understanding the stages of the engine cycle on a PV-diagram is reasonably straightforward. However, it is difficult to use equations for adiabatic expansion and compression and the ideal gas law to determine the temperature (and hence the internal energy of the air throughout the cycle). There are several reasons for this.

1) Air is not an ideal gas.
2) The mass lifter engine is not well insulated. Air warmed in the hot reservoir transfers heat energy through the cylinder walls. Thus, the air in the can and in the cylinder are probably not at the same temperature.
3) Air does leak out around the piston, especially when larger masses are added to the platform. This means the number of moles of air decreases over time. You can observe this by noting that in the transition from point **D** to point **A**, the piston ends in a slightly lower position compared to the cycle's start.