PHYSICS 171

UNIVERSITY PHYSICS LAB II

Experiment 1

Ideal Gas Laws/Heat Engine

Equipment: Thermometers (manual and digital), digital manometer, heat engine base with a moving piston, metal air chamber and tubing, hot plate.

Supplies: Two 600 ml glass beakers, 200 g mass, graph paper

A.   Objective

The objective of this experiment is to explore the behavior of ideal/real gases and the principles of operation of a heat engine

B.   Background and Theory

A gas consists of atoms (either individually or bound together as molecules) that fill their container's **volume** and exert **pressure** on the container's walls. We can usually assign a **temperature** to such a contained gas. These three variables associated with a gas—**volume, pressure, and temperature**—are all a consequence of the motion of the atoms. The **volume** is a result of the freedom the atoms have to spread throughout the container, the **pressure** is a result of the collisions of the atoms with the container's walls, and the **temperature** has to do with the kinetic energy of the atoms.

Charles' law states that at a constant pressure, the volume, V, of a fixed quantity of gas varies directly with the absolute temperature, T:
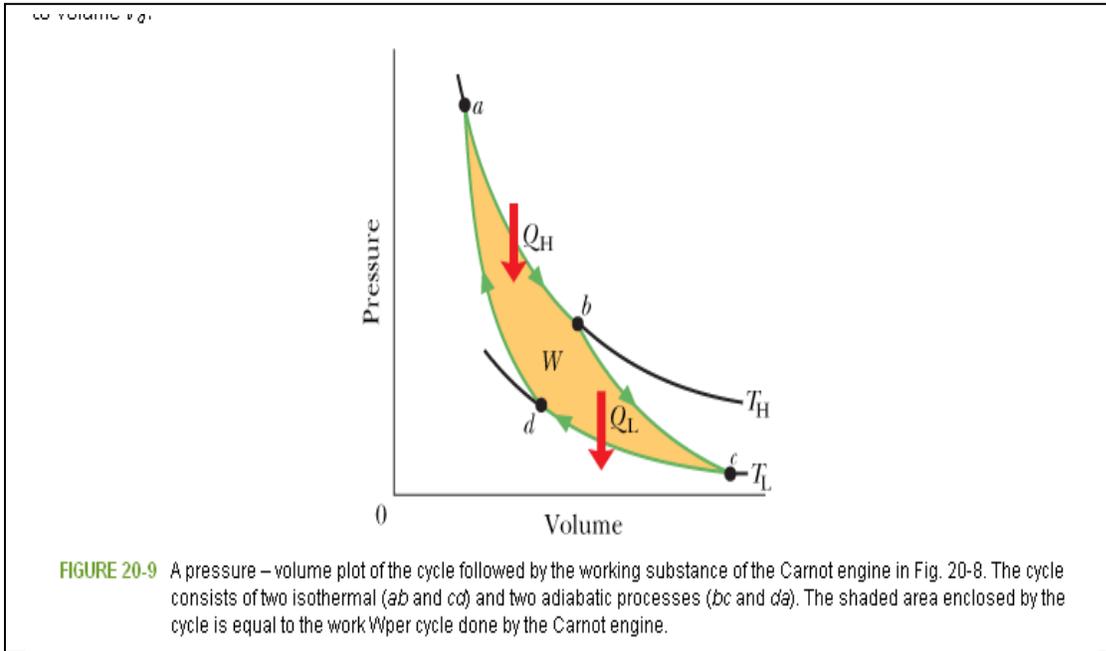
$$V = const*T$$

where V is in $[m^3]$ and T in [Kelvin].

Boyle's Law states that the product of the volume, V, of a gas times its pressure, P, is a constant at a fixed temperature. Therefore, at a fixed temperature, the pressure will be inversely related to the volume, and the relationship will be linear:

$$P = const*(1/V)$$

A **heat engine** is a device that extracts energy from its environment in the form of heat and does useful work. At the heart of every engine is a *working substance*. In a steam engine, the working substance is water, in both its vapor and liquid forms. In an automobile engine the working substance is a gasoline–air mixture. If an engine is to do work on a sustained basis, the working substance must operate in a *cycle;* that is, the

working substance must pass through a closed series of thermodynamic processes, called *strokes*, returning again and again to each state in its cycle. Carnot's engine cycle is shown below as an example.

A pressure – volume plot of the cycle followed by the working substance of the Carnot engine in Fig. 20-8. The cycle consists of two isothermal (*ab* and *cd*) and two adiabatic processes (*bc* and *da*). The shaded area enclosed by the cycle is equal to the work W per cycle done by the Carnot engine.

The **thermodynamic work**, *W,* per cycle can be estimated from the area enclosed by the respective cycle, e.g. the area enclosed by the polygon *abcd* in the P-V diagram above. Numerically W can be expressed as a function of the volume and pressure changes across the cycle *abcd* by the following expression:

$$W = \oint PdV,$$
where *W* is measured in [Joules], P in [Pascals].

Mechanical work *W* is energy transferred to or from an object by means of a force acting on the object. Energy transferred to the object is positive work, and energy transferred from the object is negative work.
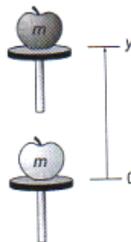

The mechanical work done in lifting a mass, *m*, though a vertical distance, *y,* (see above) is equal to *"mgy",* where "*g"* = 9.82 meters/seconds^2 is Earth's gravity, "*m"* is in [kg] and "*y"* in [meters].

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C: <u>Procedures</u>

<u>Verification of Charles' law</u>

Using the one-holed rubber stopper and plain tubing, connect the heat engine base and the metal air chamber. Close the shut-off valve on the tubing from the unused second base port. Turn the base on its side as shown below. In this position the force acting on the apparatus is the atmospheric pressure and is constant throughout the experiment.

Close the shut-off valve on the tubing from the unused port.

Hot
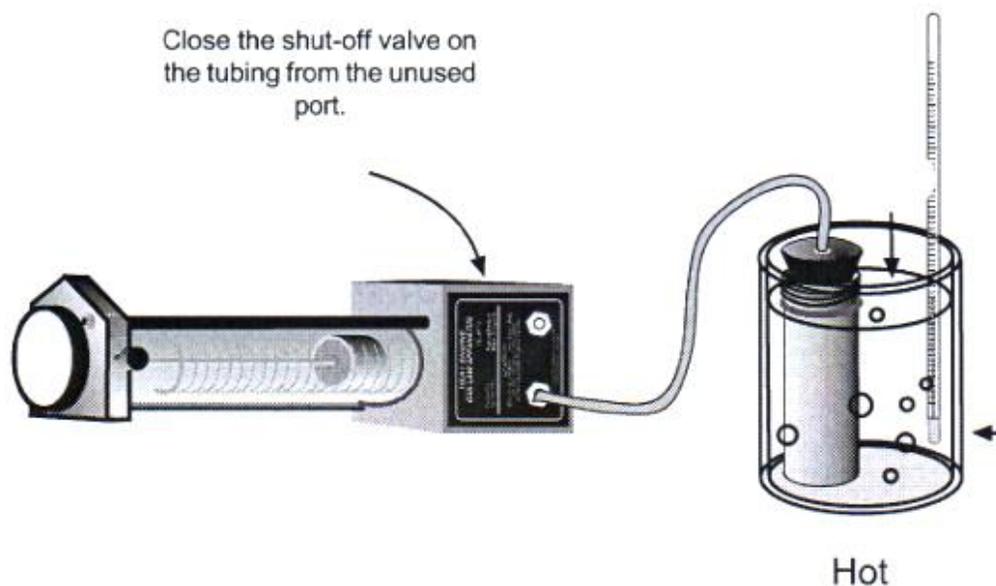
Place the air chamber and the thermometer inside a glass beaker filled with tap water. After the chamber equilibrates to the water temperate, record the temperature and the position of the piston. Put the beaker on a hot plate and turn the plate on. Temperature will start rising. Record the position of the piston at every 10 degrees temperature increase till the water starts boiling. Calculate the gas (air) volumes at the various piston positions you measured. Summarize the data with units in the respective data sheet below Make a plot of gas/air volume vs temperature. Note: the diameter of the piston is 32.5 x 10^{-3} m.

Watch out: do not touch the hot plate surface with a bare hand !

<u>Verification of Boyle's law</u>

Using the one-holed rubber stopper and plain tubing, connect the heat engine base with the manometer. Keep the unused second base port shut off (see the picture below).

Record the height of the piston and the pressure when the platform is raised to its highest position. Press the platform down to a series of levels and record the height and pressure at each level. Convert the height measurements to gas volume measurements. Summarize the data with units in the respective data sheet below. For better precision run the manometer in "Differential pressure mode" **(see Appendix 1 on page 10**). Make a graph of gas pressure vs volume.

<u>The Mass Lifter Heat Engine</u>

Using the one-holed rubber stopper and plain tubing, connect the metal air chamber to one of the ports of the heat engine base. Place the chamber inside a beaker with tap cold water. Use the second port of the base to connect the manometer. Put a 200 g mass on
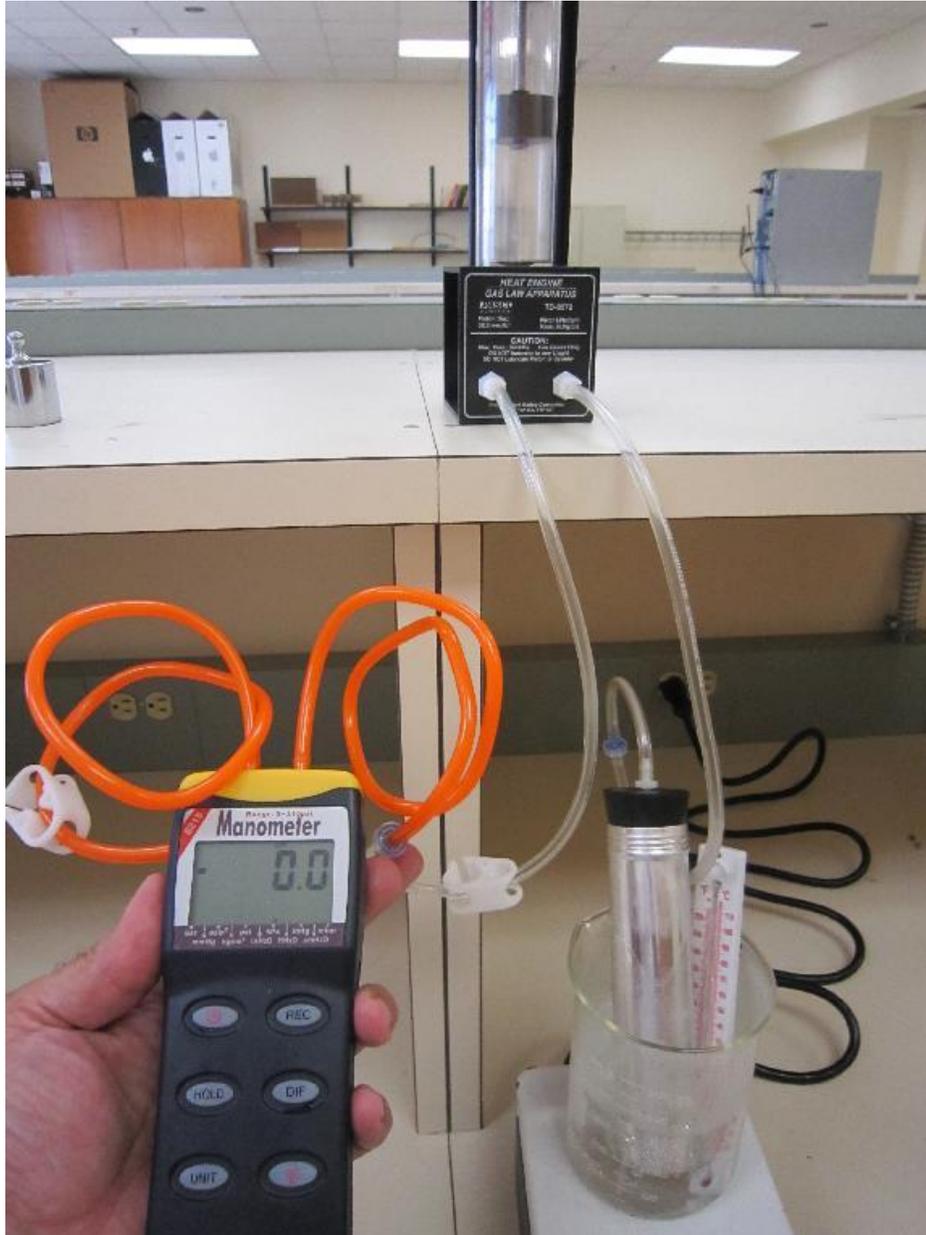

the top of the engine's platform. Remove the chamber from the beaker with cold water and place it in a beaker with boiling water (see the picture above). The temperature of the gas/air trapped inside the glass cylinder, hoses and air chamber will increase, causing the gas to expand and the platform to rise. The 200 g mass on the platform will rise

accordingly. When the mass is removed from the platform the latter will rise further since the pressure inside the glass cylinder will drop a bit. The volume of the gas inside the cylinder will decrease if the air chamber is taken out of the beaker with boiling water and put back inside the beaker with cold tap water. This will cause the platform to come down in height. The various stages of this "mass lifter cycle" are shown below.

Point A   Point B   Point C   Point D

    Cold   Cold   Hot   Hot
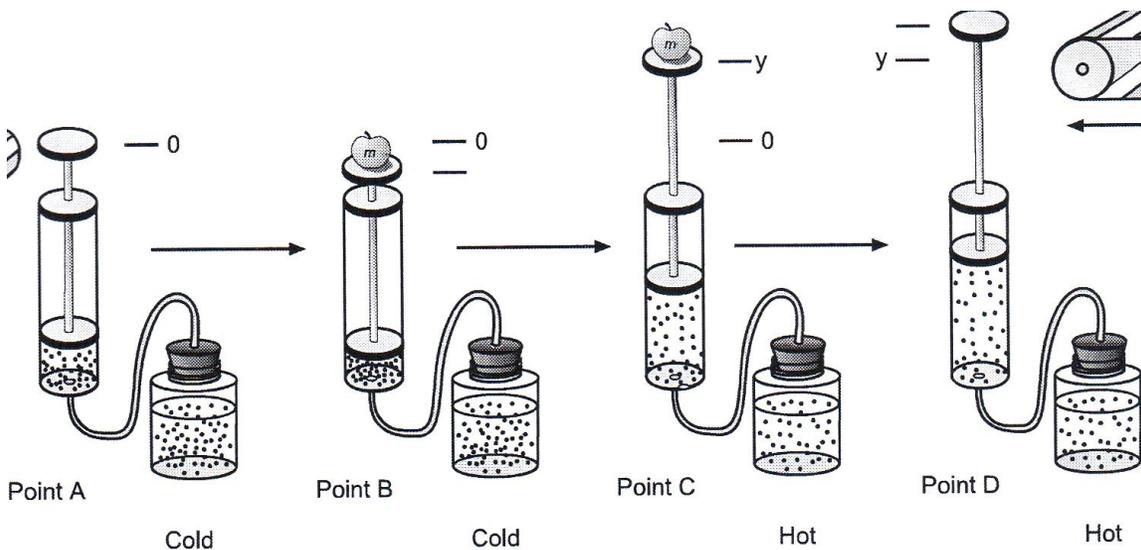
In order to calculate the thermodynamic work done during this cycle, you will need to plot a P-V diagram based on measurements of the volumes and pressures of the air trapped inside the cylinder at the points *a, b, c* and *d* in the cycle. The experiment is easier to begin with the piston resting just above the bottom of the cylinder (point *a* of the cycle above). Then proceed as depicted in the plot above. Do a few engine cycles before taking any data to be able to distinguish clearly points *a, b, c* and *d* of the cycle. Take as many measurements as needed to determine the volume and pressure of gas/air in the system at all four points in the engine cycle. Read the platform positions from the ruling on the side of the glass cylinder; then convert them into gas volume. The corresponding pressure values will be shown on the manometer display. Again, run it in "Differential Pressure Mode" for easiness of operation. Do this rapidly to avoid air leakages around the piston. Summarize the data with units in the data sheet below. Plot a P-V diagram (see the plot below, right).
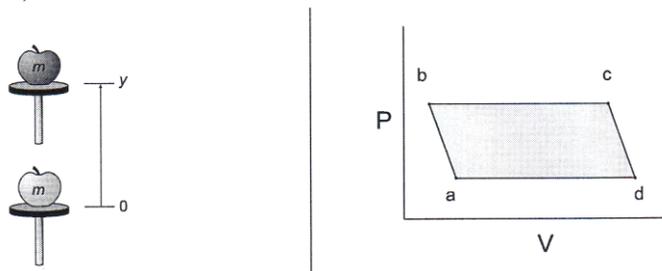
From that diagram estimate the thermodynamic work per cycle in joules and compare it with the useful mechanical work (left in the plot above) done in lifting the 200 g mass. Comment on the outcome of the comparison.

Data Sheet – Charles' law

Temperature* (degrees Celsius)	Temperature [K]	Piston position [mm]	Gas/air volume [m^3]
30			
40			
50			
60			
70			
80			
90			
100			

*Details of how to use digital thermometer are given in Appendix 2 on page 11

Comment on the data points; e.g. what dependence do the show, if any ?

Data Sheet – Boyle's law

Piston position [mm]	Gas/air volume [m^3]	Pressure [manometer units]	Pressure [Pa]

Comment on the data points; e.g. what dependence do the show, if any ?

The Mass Lifter Heat Engine

Point *a* of the cycle (air chamber in cold tap water) :

$P_a =$ [Pa]
$V_a =$ [m^3]

Point *b* of the cycle:

$P_b =$ [Pa]
$V_b =$ [m^3]

Comment on what happens when 200 g mass is added to the piston platform:

Point *c* of the cycle:

$P_c =$ [Pa]
$V_c =$ [m^3]

Comment on what happens when the air chamber is placed in boiling water ?

Point *d* of the cycle:

P$_d$ =   [Pa]
V$_d$ =   [m^3]

Comment on what happens when the 200 g mass is removed from the piston platform:


Comment on what happens when the air chamber is returned to the beaker with cold water (i.e. to point *a* of the cycle):

Explain how the thermodynamic work was estimated from the P-V (*abcd*-cycle) diagram:

Explain how the mechanical work was computed. Show your work:

Appendix 1. Digital manometer operation summary

For your convenience, the meter defaults the setting used in the last operation. The following lists the operation for each function key.
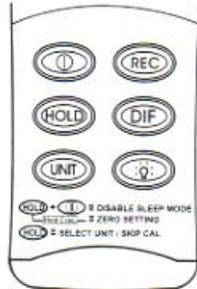
Ⅰ Turns instrument on (Default set-ting) and off.

REC Press momentarily and relative clock starts in the lower right screen.
REC is displayed in the middle left of (Fig. B) other button functions are locked out except **Power** and **Backlight.**
Press momentarily again and the unit cycles through **MAX** (Fig. C) and **MIN** (Fig.D) and back to current pressure ; the record mode is displayed on the LCD. Press and hold REC for 3 seconds to turn off the record function to the normal mode.

Fig. B ➔

Fig. C ➔

Fig. D ➔
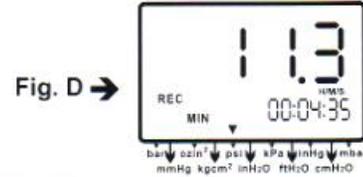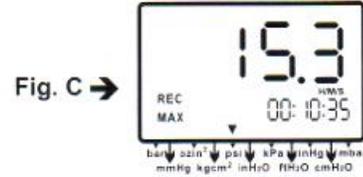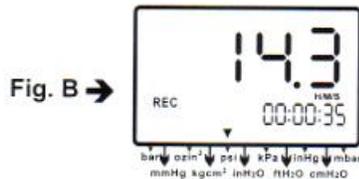
HOLD Press momentarily to freeze the pressure reading . (Fig.E)

Fig. E ➔
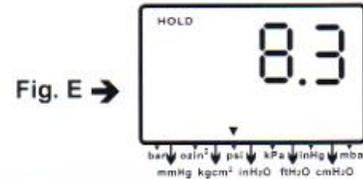
DIF Press momentarily ,**DIF** appears on top of the LCD and the display indicates the relative zero (Relative zero causes the value of the display to show as "0.0")-only the amount of pressure change will be indicated. Press momentarily again and the unit returns to the normal mode of pressure differential (see Fig.F).

Fig. F ➔
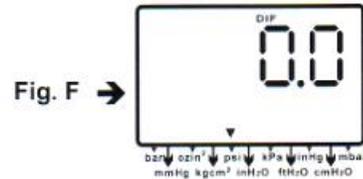
Appendix 2 Digital thermometer operation summary

Measuring Temperature
See Figure -10-

1. Set the Function Switch to °**C** or °**F**.
2. Connect the K-type thermocouple to a TEMP adapter (XR-TA).
    Match the polarity of the adapter to the polarity of the thermocouple.
3. Connect the TEMP adapter to the **V**Ω→⊢ and **COM** inputs.

Note: The 34XR-A is compatible with all K-type thermocouples. The K-type bead thermocouple supplied with the meter is not intended for contact with liquids or electrical circuits.

4. Expose the thermocouple to the temperature to be measured.
5. Read the display.