# Unit 01-2 Heat Engine:

## Introduction：

Gases can exchange energy with the surrounding environment by doing work. If there is a change in volume of a gas at a constant temperature, this work process at constant temperature is called an isothermal process. On the other hand, if the pressure is constant, it is called an isobaric process. In this experiment, the experiment attempts to verify the relationship between the potential energy ($mgy$) of the material displacement (y) and the net thermodynamic work ($PV$) of the gas during thermal cycling using the operation of a real heat engine. The heat engine setup consists of a hollow cylinder with a graphite piston that can move along the axis of the cylinder (friction can be ignored when friction is small). There is a platform on the piston for lifting mass and the cylinder is connected to the gas chamber through a flexible hose (a small container sealed by a rubber plug, the rubber plug can be alternately placed in a hot bath and a low temperature bath). By placing the gas chamber in heat baths with different temperature differences, we can control the expansion of the gas and raise or lower the object on the cylinder. A schematic diagram of the heat engine setup is shown as Fig.1.


Fig.1 heat engine.

## Process：

1. Verifying the thermal cycle curve with a real heat engine.
    - Verifying the thermal cycle curve with a real heat engine (isothermal, isobaric, expansion and compression), the thermal cycle process is shown in Figure 2. The actual operation diagram is shown in Figure 3.

- Isothermal compression: Transition from **a to b** by applying external mass (~200 g, adjustable with the volume of the gas) on top of the platform to compress the gas in the piston.
- Isobaric expansion: Transition from **b to c** by taking the air cylinder from the cold water bath and then placing it in the hot water (high-temperature reservoir).
- Isothermal expansion: Transition from **c to d** by keeping the chamber in the hot water (high-temperature reservoir) and removing the external mass on the platform.
- Isobaric compression: Transition from **d to a** by taking the air piston cylinder from the hot water and then placing it in the cold water.

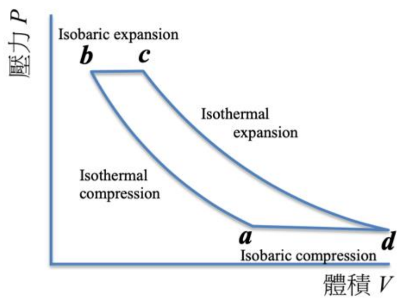


Fig. 2. The thermal cycle processes.

2. Calculating work with actual $PV$ curve (Figure 3 shows the experimental setup for the thermal cycle).
    - Measure the air pressure and expanding (compressing) volume in the system at all four points in the thermal cycle using the steps outlined in Part 1. Make sure to record the initial height of the cylinder for calculating the volume.
    - Use the measured values to calculate the system volume at points A, B, C, and D. (Consider the air volume in the pipe and the air cylinder!)
    - Use the ideal gas law to verify the process from **A to B** and from **C to D** as being approximately isothermal.
    - Draw the PV diagram of the thermal cycle and label each point on the cycle. Mark the approximate isothermal and isobaric lines on the PV table.
    - Calculate the work done by the gas during the process from **B to C to D**, $W_1$, in the thermal cycle.
    - Approximate the thermal cycle PV diagram as a quadrilateral and calculate the area of the quadrilateral, $W_2$.

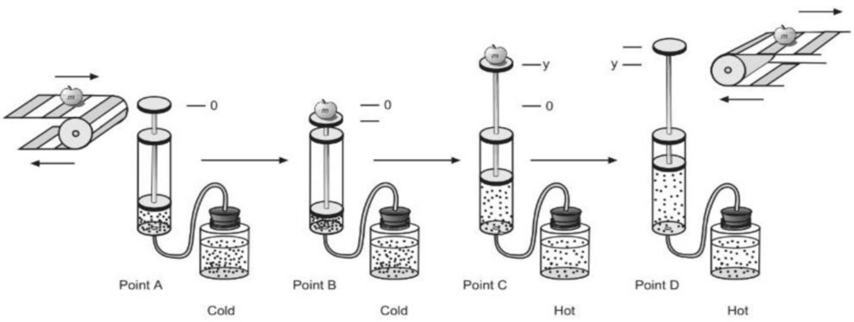

Fig. 3. The experimental setup for the thermal cycle

## **Precautions**：

- ✧ To prevent damage to the instrument, during the experiment, hold the gas law apparatus with one hand and use the other hand to strike the piston with appropriate force.
- ✧ After closing the valve, check if the piston is sliding down. If the piston still slides down, the main reason is that the valve is not fully closed and not connected to the low-pressure sensor.
- ✧ In this experiment, if a larger object is lifted, the leak rate will increase, so consider the additional weight of the object.
- ✧ In this experiment, for safety, avoid using hot water with a temperature that is too high in the high-temperature calorimeter.

## **Discussion Prompts**：

1. Why is the temperature of water increased faster when boiling with a lid on compared to without a lid? Try to explore this phenomenon using the specific heat ratio.
2. If the experimental gas is changed to helium, how will the slope in the $T^2$-h graph change? Explain.
3. What is the main composition of air? In this experiment, if air is assumed to be a diatomic molecule, why is this assumption made? Explain.
4. Can a closed thermal cycle curve be completed on the *P-V* graph in the calorimeter experiment? Explain the behavior of the curve.
5. Explain the meanings of $W_1$ and $W_2$."