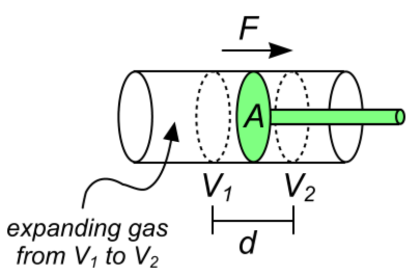
Lapse Rate. Prof. Ruiz (Doc), UNC-Asheville (1978-2021), DoctorPhys on YouTube.
Prerequisites: Chemistry, Physics I, II. Calculus I, II, III. Thermodynamics.

Chapter E. Thermodynamics. Thermodynamics is the study of heat, work, and energy. The key idea we will study in this chapter is heating a gas and letting it expand to do work.

1. Energy. We have already addressed energy in the previous chapter. We derived the following equations. We found that the energy of an ideal gas of point particles is proportional to the temperature.

$$\boxed{U = N\frac{1}{2}m\overline{v^2}} \qquad \boxed{U = \frac{3}{2}NkT} \qquad \boxed{U = \frac{3}{2}nR^*T}$$

2. Work. Work W is defined in introductory physics as force F times distance d when the force is applied along the direction of motion: $W = Fd$.

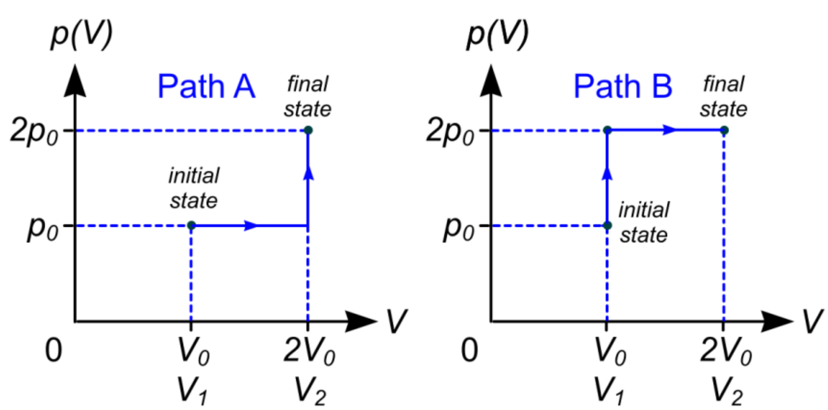


In the left figure a gas expands from volume V_1 to V_2 pushing on a piston which moves from the V_1 position to the V_2 position. The area of the green piston plate is A. The gas is expanding since we are heating it.

The work done by the gas is $W = Fd$, where F is the force the gas exerts on the green piston plate. We use the equation that pressure is force per area: $p = \frac{F}{A}$ in the form $F = pA$.

$$W = Fd \quad \Rightarrow \quad W = pAd \quad \Rightarrow \quad W = p(V_2 - V_1) \quad \Rightarrow \quad W = p\Delta V$$

The work is given by the area under a pressure-volume graph. We consider two different paths below in order to go from an initial state to a final state. Note that no work is done when $\Delta V = 0$.



For Path 1: $W_1 = p\Delta V$ => $W_1 = p_o(V_2 - V_1)$ => $W_1 = p_o(2V_o - V_o)$ => $W_1 = p_oV_o$

For Path 2: $W_2 = p\Delta V$ => $W_2 = 2p_o(V_2 - V_1)$ => $W_2 = 2p_o(2V_o - V_o)$ => $W_2 = 2p_oV_o$

Important Observation: The work done depends on the path taken.

Since work is path dependent, there is not such thing as a $W_{initial}$ or a W_{final}. Therefore, we cannot write ΔW or dW. But we need some way to represent the work done even though it is path dependent. So the following notation can be found in texts.

$$đW \quad \bar{d}W \quad d'W \quad \delta W$$

I encountered $đW$ when I was a physics student. I find δW often used in meteorology. I will use δW. NEVER use dW.

3. The First Law of Thermodynamics. The first law of thermodynamics in words is

change in energy of the gas = heat added minus the work done by gas expansion.

Since the energy $U = \frac{3}{2}nR^*T$ is defined for a gas state we can write a change as $\Delta U = \frac{3}{2}nR^*\Delta T$ where the number of moles of the gas does not change. Think of our gas with a fixed number of moles in a piston chamber. The first law now becomes

ΔU = change in heat minus work done.

Let Q to represent the heat and W to represent the work. Then the first law becomes

$$\Delta U = Q - W.$$

Below we consider infinitesimal changes, being careful with how we handle heat and work.

dU = change in heat – δW.

We can also write

change in heat = $dU + \delta$W.

The convention is to use Q for heat. The change must be an inexact differential because of the δW on the other side of the equation. Acceptable notations are below. NEVER use dQ.

$$đQ \quad \bar{d}Q \quad d'Q \quad \delta Q$$

Therefore, we express our equation change in heat = $dU + \delta$W as

$$\delta Q = dU + \delta W.$$

Let's go back to our form of the first law with the energy term on the left side.

$$dU = \delta Q - \delta W$$

We can express the change in work δW with variables that are exact differentials: $\delta W = pdV$.

But never forget that the combination pdV is path dependent and is not an exact differential. The first law now takes on the form

$$dU = \delta Q - pdV \ .$$

Divide both sides by the volume V .

$$\frac{dU}{V} = \frac{\delta Q}{V} - p\frac{dV}{V}$$

With $du = \dfrac{dU}{V}$, $\delta q = \dfrac{\delta Q}{V}$, and $d\alpha = \dfrac{dV}{V}$, we obtain

$$du = \delta q - pd\alpha \ .$$

Remember the lowercase variables are intensive variables and we reserve lowercase "v" for vapor.

This equation is our 12th review equation.

(12) $\boxed{\delta q = du + pd\alpha}$