

Lecture 4: Energy in Thermal Physics

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4.1 Compression Work

$$VT^{f/2} = \text{const.} \quad (4.1)$$

$$V^\gamma P = \text{const.} \quad (4.2)$$

where $\gamma = \frac{f+2}{f}$ is called adiabatic exponent.

Exercises

(Problem 1.38):

Two identical bubbles rise from the bottom of a lake to its surface.

Bubble A rises quickly (adiabatic condition).

Bubble B rises slowly (isothermal condition).

Which bubble is larger in the end?

(Problem 1.40):

In Lec02, we have determined that

$$\frac{dP}{dz} = -\frac{mg}{kT}P \quad (4.3)$$

and obtained the pressure P as a function of height as follows,

$$P(z) = P(0) \exp(-mgz/kT) \quad (4.4)$$

1) show that T and P has the following relation

$$\frac{dT}{dP} = \frac{2}{f+2} \frac{T}{P} \quad (4.5)$$

2) find a formula for dT/dz like dP/dz .

3) estimate the temperature at the peak of Mount Everest (8848 km).

4.2 Heat Capacities

The heat capacity of an object is the amount of heat needed to raise its temperature,

$$C = \frac{Q}{\Delta T} = \frac{\Delta U - W}{\Delta T} \quad (4.6)$$

Specific heat capacity is a more fundamental metric,

$$c = \frac{C}{m}. \quad (4.7)$$

There are two types of circumstances

1. constant volume, C_V
2. constant pressure, C_P

Obviously, C_P is more representative than C_V . According to the equipartition theorem,

$$C_V = \frac{\partial U}{\partial T} = \frac{\partial}{\partial T} \left(\frac{NfkT}{2} \right) = \frac{Nfk}{2} \quad (4.8)$$

Under constant pressure,

$$C_P = \frac{\partial(U - W)}{\partial T} = \frac{\partial}{\partial T} \left(\frac{NfkT}{2} \right) - \frac{\partial W}{\partial T} \quad (4.9)$$

$$\frac{\partial W}{\partial T} = -P \frac{\partial V}{\partial T} = -P \frac{\partial(NkT/P)}{\partial T} = -Nk \quad (4.10)$$

therefore,

$$C_P = C_V + Nk. \quad (4.11)$$

using ideal gas law.

Discussions:

1. What's the relation between C_V and C_P for solids?
2. C_V of 1 mole of H_2 gas as a function of temperature (see Figure 4.1)
3. C_P of 1 mole of elemental solids as a function of temperature (see Figure 4.2)

Exercises

(Problem 1.44): Look up the table of thermodynamic data at room temperature. Browse through the C_P values in this table, and understand them according to the equipartition theorem.

Type	Examples	Ideal Value	Anomaly
monoatomic gas			
diatomic gas			
polyatomic(linear) gas			
polyatomic gas			
Elemental solid			
Binary solid			

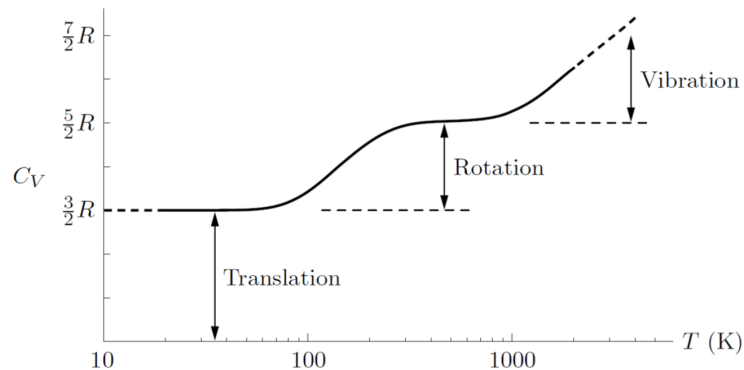


Figure 4.1: Heat capacity at constant volume of one mole of hydrogen (H_2) gas. Note that the temperature scale is logarithmic.

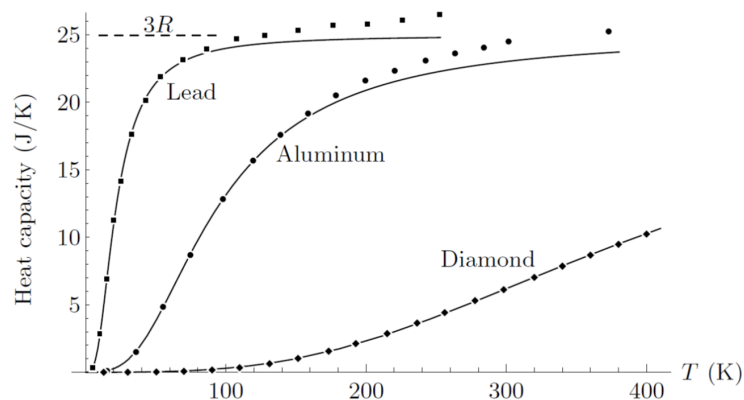


Figure 4.2: Measured heat capacities at constant pressure (data points) for one mole each of three different elemental solids.

4.3 Enthalpy

Constant pressure processes occur quite often in chemical reactions and phase transformations. Keeping track of the work done during these processes gets to be a pain. Any idea to make it more convenient? Instead of talking about the energy, we can agree to add the work due to PV in the given environment. This results in a new quantity called the enthalpy (H),

$$H = U + PV \quad (4.12)$$

Conveniently, we can express

$$C_P = \left(\frac{\partial H}{\partial T} \right)_P \quad (4.13)$$

Think about

1. diamond and graphite under high pressure
2. formation enthalpy of H_2 and O_2 gas combine to water