Today

I. First take home exam due Friday by midnight
II. Our Stamina Breaks for the Semester: We will take Friday Oct 23rd off, Wed Nov 25th, and Fri Nov 27th.
III. Last Time
IV. Chemical Potential: An Example
V. Begin Discussion of Heat Engines

I. On Friday we discussed joint thermal and diffusive equilibrium. We saw that diffusive equilibrium is achieved between two systems A and B in diffusive contact when $\mu_A = \mu_B$. Normally this is accompanied by exchange of energy and hence thermal equilibrium, so $T_A = T_B$. (Diffusive equilibrium is not necessarily characterized by equal number of particles! This is correct when we have, say, an ideal gas and the two subsystems have equal volume.)

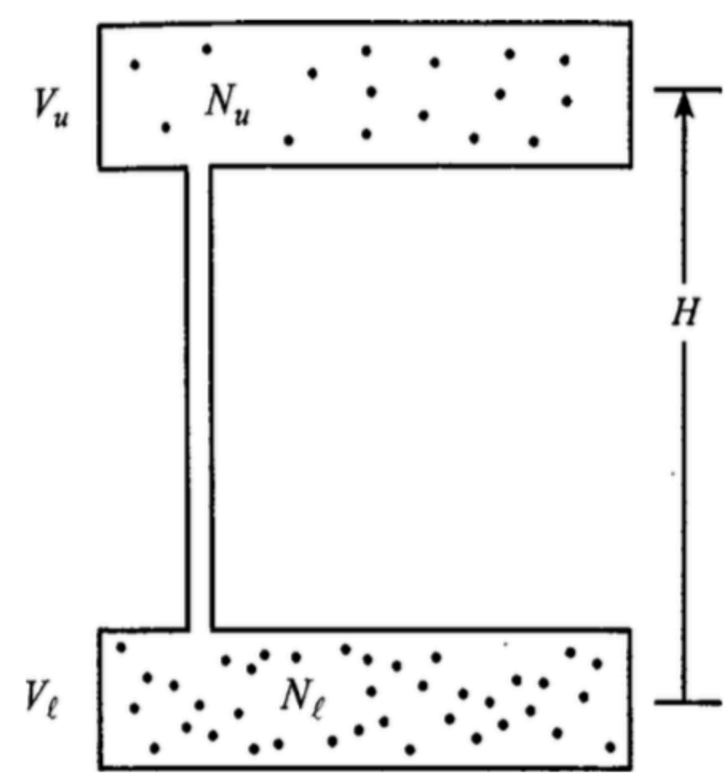
I. What's the definition of chemical potential?

$$\mu = -T\left(\frac{\partial S}{\partial N}\right)_{V,U}.$$

Guillermo also introduced us to a generalized thermodynamic identity:

$$dU = TdS - PdV + \mu dN.$$

II. Let's think about an example of chemical potential in the context of gravity. On the HW you'll show that



$$\mu(z) = -kT\ln\left[\frac{V}{N}\left(\frac{2\pi mkT}{h^2}\right)^{3/2}\right] + mgz.$$

[Recall we had a second formula

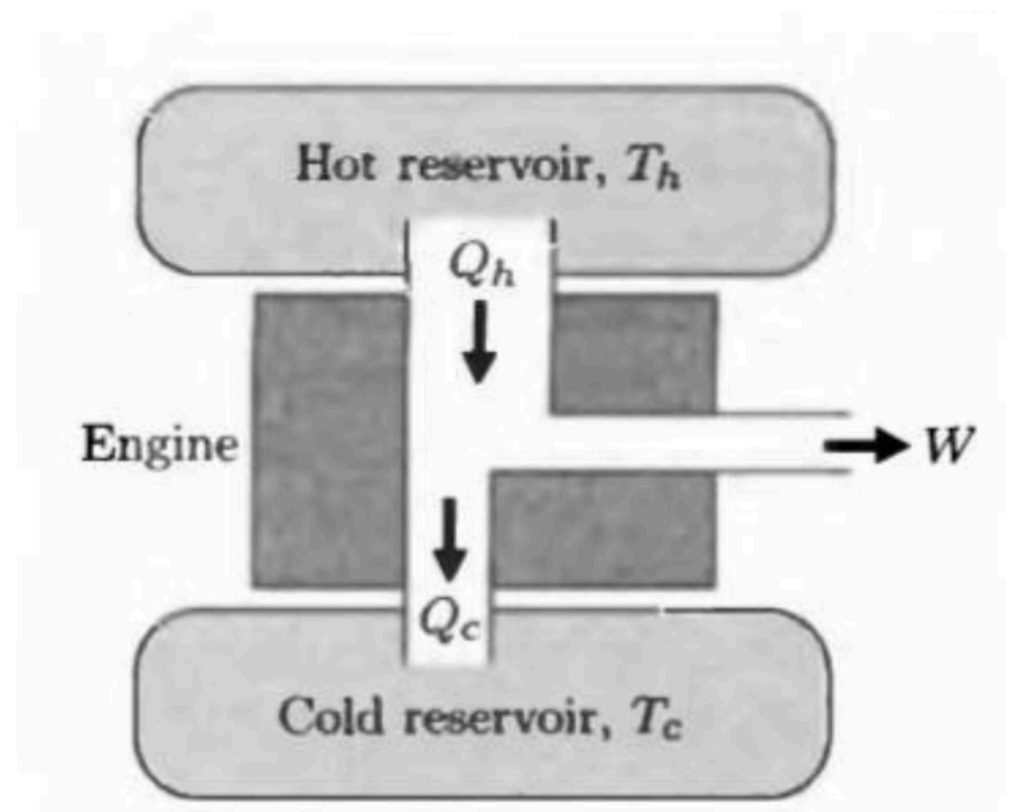
$$\mu = \left(\frac{\partial U}{\partial N}\right)_{V,S}.]$$

II. We can generalize the thermodynamic identity

$$dU = TdS - PdV + \sum_i \mu_i dN_i.$$

III. Heat engines are an extremely important practical application of thermodynamics. Let's define efficiency first. A definition of efficiency always depends on what you want. In the case of an engine we want work out. In a refrigerator we want to be able to transfer heat. For engines, we want efficiency

$$e \equiv \frac{\text{benefit}}{\text{cost}} = \frac{W}{Q_h}.$$



Looking at the engine, what does conservation of energy tell us?

$Q_h = Q_c + W \implies W = Q_h - Q_c.$

Then $e = \dfrac{Q_h - Q_c}{Q_h} = 1 - \dfrac{Q_c}{Q_h}$

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Then $e = \dfrac{Q_h - Q_c}{Q_h} = 1 - \dfrac{Q_c}{Q_h}$. We'd like to characterize this ratio, and to do so we turn to entropy. In particular, Clausius' relation $\dfrac{Q_c}{T_c} \geq \dfrac{Q_h}{T_h}$, this means that $\dfrac{Q_c}{Q_h} \geq \dfrac{T_c}{T_h}$. Putting this into our efficiency formula we have

$$e \leq 1 - \frac{T_c}{T_h}$$