

# PHYS 301

## Thermodynamics and Statistical Mechanics

Worksheet #9  
Tuesday March 10 2026

### Question 1.

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**Extensive and Intensive quantities:** We just saw in class that quantities like volume  $V$ , energy  $E$ , entropy  $S$ , and particle number  $N$  are *extensive* quantities: they scale with the size of the system. On the other hand, the temperature  $T = (\partial S / \partial E)^{-1}$  does not scale with the size of the system and is thus said to be an *intensive* quantity.

- (a) Using similar arguments to what we just discussed in class, determine whether the pressure  $P = T(\partial S / \partial V)$  and chemical potential  $\mu = -T(\partial S / \partial N)$  are extensive or intensive quantities.
- (b) Determine whether the Helmholtz free energy  $F = \langle E \rangle - TS$  is an intensive or extensive quantity. Use this to determine the scaling of  $F(T, V, N)$  as the volume and particle number are scaled by a constant  $\lambda$

$$F(T, \lambda V, \lambda N) = ? \quad (1)$$

- (c) Is the grand potential  $\Phi(T, V, \mu) = F - \mu \langle N \rangle$  extensive or intensive? How does the grand potential scale as the volume is scaled by a constant  $\lambda$

$$\Phi(T, \lambda V, \mu) = ? \quad (2)$$

Use the above to argue that

$$\boxed{\Phi = -PV}, \quad (3)$$

a very simple expression indeed!

- (d) Another “free” energy that is sometime useful is the Gibbs free energy, define as  $G(T, P, N) = F + PV$ , which is naturally a function of  $T$ ,  $P$ , and  $N$ . Use a similar argument to part (c) to show that  $G$  admits the very simple form

$$\boxed{G = \mu N}. \quad (4)$$