Physics 6351 Professor Scalise
Homework Assignment #1 Spring 2025

1. Read Kardar chapter 1. Did you read all the pages?
2. Calculate:
   (a) the average translational kinetic energy of a neon atom at room temperature.
   (b) the average translational kinetic energy of a golfball at room temperature in a gas of golfballs. (Pretend that the golfballs can not spin, vibrate, heat up, or store energy in any way other than translating.)
   (c) Why is that parenthetical disclaimer above necessary?
   (d) the root-mean-square speed of a neon atom at room temperature. What is the Mach number for this speed?
   (e) the root-mean-square speed of a golfball at room temperature in a gas of golfballs.
3. (a) How many degrees of freedom are active in air (N_2 and O_2) at room temperature? What can the diatomic molecules do to store energy? What can they not do?
   (b) Calculate the thermal energy in a cubic meter of air at room temperature and one atmosphere.
   (c) Compare this energy to a car crash.
   (d) Is it possible to extract this energy to charge your mobile phone also at room temperature? Explain.
4. 500 grams of ice cubes at 0°C are placed in 1 liter of water at 20°C. The system then comes to equilibrium with no heat exchange with surroundings. Does the ice melt completely? If yes, find the temperature of the water in equilibrium. If not, find out how much ice remains in equilibrium.
5. If 100 grams of boiling water is added to a 20-gram aluminum cup containing 50 grams of water at 20°C, what will be the equilibrium temperature of the full cup?
6. Suppose there exists a relation among three coordinates x, y, and z such that $f(x, y, z) = 0$. What is
$$\left(\frac{\partial x}{\partial y}\right)_z \left(\frac{\partial y}{\partial z}\right)_x \left(\frac{\partial z}{\partial x}\right)_y \quad ?$$
   Show all work.

Bonus

1. Explain clearly why Boltzmann's constant k_B is not a universal constant like the speed of light c or Planck's constant h or Newton's constant G. That is, alien scientists in a distant galaxy would discover the speed of light; they would express it in different units, but it would be the same speed that we know. Similarly, the aliens would discover something like h, perhaps $2h$ or h/π, and it might be called ZbymG's constant, but Earth scientists would recognize the quantum of action. Not so with k_B. Why not?

2. Even at low density, real gases are not ideal. One way to account for deviations from ideal behavior is the virial expansion

$$PV = nRT\left[1 + \frac{B(T)}{(V/n)} + \frac{C(T)}{(V/n)^2} + \cdots\right]$$

For the van der Waals gas with equation of state

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT,$$

find the first two virial coefficients $B(T)$ and $C(T)$ in terms of a and b. Assume $\frac{nb}{V}$ is small and expand.