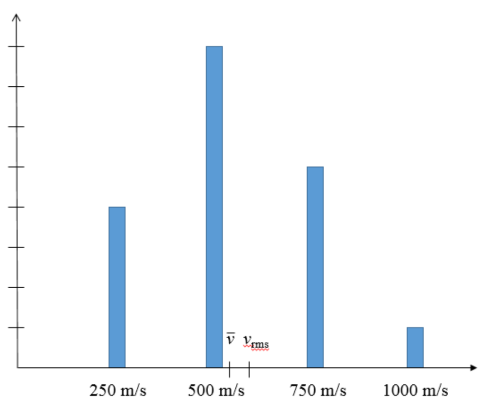
Selected Answers – Thermodynamics Assignment

1. a. While the water is in a liquid phase, molecules are relative close to one another and are bound by relatively weak forces of attraction. As the temperature increases the random motion of the molecules increases in terms of speed – the kinetic energy is increasing.
   b. Once boiling commences the water is undergoing a phase change from liquid to gas. The molecules are moving much farther apart than when in a liquid state. This is analogous to a satellite escaping the gravity of the Earth – the molecules escape the forces that attract one another. This is an increase in potential energy (analogous to an object moving away from Earth).
2. a. "Ice-cold water" would 0 °C initially. The counter would be at room temperature, roughly 20 °C. Given time, the water would gain energy from the counter and the room environment. This occurs due to random collisions between molecules in the water and in the counter. Eventually the water reaches thermal equilibrium at 20 °C, so its change is that amount.
   b. The water never reaches the boiling point of 100 °C. But even at 20 °C there are randomly some molecules that might reach an "escape velocity" (see above). A molecule moving fast enough, propelled by chance collisions, moves far enough away from other water molecules in the drop that it enters the air and does not return to the drop. Over time this process occurs randomly to all the molecules in the drop.
3. a. If the temperature of the water decreases, then the temperature of the metal block must increase. As long as the decrease in internal energy of water equals increase in internal energy of metal block, then it does not violate the principle of conservation of energy.
   b. Because the energy transfer is a result of random collisions between atoms in the metal and the molecules of water, and because the atoms in the metal are more energetic on average, the most likely outcome of each collision is transfer of energy from metal to water. Over time the most energetic particles will lose energy and the least energetic particles will gain energy until both substances have particles with the same average translational kinetic energy, and hence the same temperature.
   c. Final temperature of the metal must also settle at 13.0 °C. By zeroth law, If the water has reached thermal equilibrium with the thermometer (which now shows 13.0 °C) and it is also in thermal equilibrium with the metal, then the metal must also be in thermal equilibrium with the thermometer and be at the same temperature as it.
4. The air at top and bottom of the house is at very nearly the same pressure. But air at higher temperature has greater volume by $PV = nRT$ per given amount n. Thus higher temperature results in less density. The less dense air is "buoyant" and therefore it is pushed up by the cooler and denser air.
5. a. 43.7 g, 9.4×10^{23} molecules
   b. 194 kPa (28.1 psi) (better put some air in the tires!)
   c. Area increases by about 14%, which increases rolling resistance.
   d. 4.0 grams or 8.6×10^{22} molecules
6. 14.3%
7. 9.6 mm

8. a. 23.9 million
   b. 4×10^{-17} Pa
   c. 270 m/s
9. a. 3.9×10^{6} K, 0.16 nPa
   b. The gas laws are based on the assumption that particles are moving randomly. Because the protons are moving in a concerted fashion (like a "wind") it is not the same thing. What was done here would be a little like trying to find the temperature and pressure of the air on Earth based on the speed of the wind instead of the random speeds of the particles that make up the wind.
   c. At the speed given, assuming the body has an area of 0.5 m^2, 465 billion protons would hit you every second. If the protons rebound elastically the force of the "wind" would be 0.5 nN. If instead the body absorbs all of the energy of the protons it would amount to only about 40 μJ of "heat" per second. My educated guess – you wouldn't feel it, nor would it burn you. (Though high speed particles can damage DNA in cells, which can be bad…)
10. a. 7.0×10^{-26} kg (42 u), 1.5×10^{-20} J, 660 m/s (assuming all molecules are the same)
   b. The mass of CO_2 = 44 u, which is consistent with the 42 u found in part (a) but indicates that the atmosphere is not quite pure carbon dioxide, but also must contain a relatively small amount of a lighter gas. (Look it up – 96% CO_2 and 4% N_2)
   c. 47 N (about 10 pounds of force, which on Venus would make you feel 7% lighter)
11. $P = \frac{1}{3}\rho v^2$
12. a. $c_V = 3k/2m$ (only if there is no change in volume)
   b. 3120 J/kg·K
   c. 4400 J
13. a. 540 m/s
   b. 580 m/s
   c. 

14. a. 760 W
   b. 14 minutes
   c. 32 W
15. a. 628 W
   b. 170 °C

16. a. $R_t = L/kA$

    b. Yes, equivalent thermal resistances could be found by $R = R_1 + R_2$ for series and $R^{-1} = R_1^{-1} + R_2^{-1}$ for parallel. This can be derived using $\Delta T = R_t(Q/\Delta t)$ in the same way the derivations for electrical resistance can be done with Ohm's Law $\Delta V = IR = R(\Delta q/\Delta t)$.
17. a. 82 W

    b. 0.33 C° is ΔT for the sheetrock for given conditions with either side hotter because it is proportional to the heat rate regardless of direction.

    c. 3.4 cm additional thickness
18. a. 860 MW

    b. One major problem with this solution is that it assumes that *all* of the air inside the balloon is at the exact same temperature and in direct contact with the nylon material. Air itself if a very poor conductor of heat and a good insulator. So, the heat "injected" into the center of the balloon by the burner takes time to spread outward.
19. a. The cold seeping in is actually heat leaving your body. This causes the temperature of your body to decrease.

    b. The metal wrench is a better conductor of heat than wood. Therefore heat and internal energy from your body is more rapidly removed by the wrench.

    c. Besides conduction there is also radiant heat. Your body is radiating heat in the form of infrared radiation, which also reduces the internal energy and temperature.