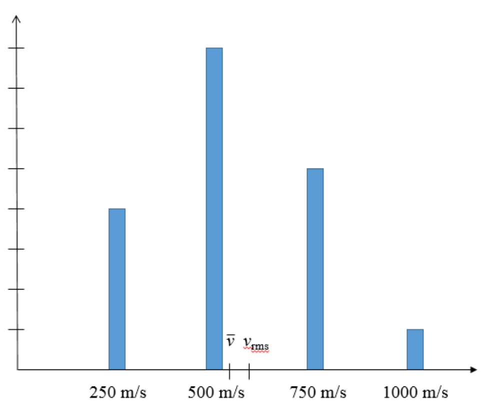
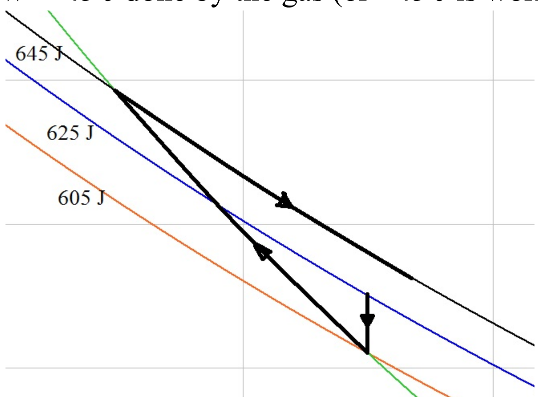
Selected Answers – Fluids Assignment

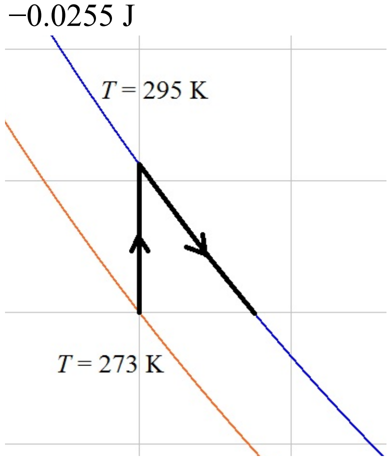
1. a. While the water is in a liquid phase, molecules are relative close to one another and are bound by relatively weak forces of attraction. As the temperature increases the random motion of the molecules increases in terms of speed – the kinetic energy is increasing.
   b. Once boiling commences the 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. 13.3%
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.
20. a. An isothermal process in which the temperature remains constant would involve heat and work. If the gas is compressed by the piston then work has been done, which would tend to increase the internal energy, but if temperature remains constant an equal amount of heat must be allowed to escape such that there is no change in internal energy.
    b. An isobaric process might involve subjecting the cylinder to heat but allowing the piston to move so that the pressure remains constant and the volume, temperature, and internal energy all increase.
    c. An isovolumetric (or isochoric) process might involve subjecting the cylinder to heat but not allowing the piston to move so that the volume remains constant and the pressure, temperature, and internal energy all increase.
    d. An adiabatic process requires that no heat go in or out of the gas. Insulating the cylinder and/or making a rapid change so there is little time for heat to occur would promote this. Rapidly compressing the air with the piston would require work that would account for increase in internal energy.

21. a. $Q = -20$ J
    b. $U = 640$ J
    c. $W = 45$ J done by the gas (or −45 J is work done on the gas)
    d. 

22. a. 3.04 J
    b. 0.415 J
    c. 0.277 J
    d. 0.692 J
23. a. 0.037 J
    b. 109 kPa
    c. 3.24 cm^3
    d. 0.0255 J
    e. −0.0255 J
    f. 

    The actual work would be area under the curve of a PV = constant hyperbolic curve. This would be a little less than calculated, because the curve is concave downward.
24. a. 5 K (final temp is 305 K)
    b. 0.203 J
    c. 0.204 J
    d. Because the work done on the gas is very nearly equal to the increase in internal energy is it consistent with an adiabatic process because the heat is essentially zero, especially allowing for uncertainty in the values.

25. a. 7.25×10^{21}
   b. 450 K (occurs at 150 kPa, 300 cm^3)
   c. 15 J work done *by* gas
   d. ≈ 12.5 J (more exact = 12.2 J) work done *on* gas
   e. ≈ 6.7% (more exact = 7.5%)
26. a. *PV* diagram is a rectangle with process going clockwise.
   b. Initially: $PV = NkT$; $U = {}^3/_2 NkT = U = {}^3/_2(PV)$. When pressure and volume both double the internal energy is quadrupled from its initial state: 4×1.5 = 6, so $U = 6PV$.
   c. Net work is area of rectangle = width × height; $W_{net} = (2V - V)\times(2P - P) = PV$.
   d. eff = 2/13; eff = 15.4%
27. a. The cube's temperature would increase if the temperature of the water decreased and energy flowed from the water into the cube. As long as the increase in internal energy of the cube equals the decrease in internal energy of the water it would satisfy the 1st Law.
   b. Heat never flows from lower to higher temperature is part of the Clausius statement of the 2nd Law. Also it would constitute a "magical heat pump" where the water is cooled like being put in a refrigerator, but no work is being done – not possible by the Kelvin-Planck statement of the 2nd Law.
   c. Because of the random motion of atoms and molecules there is a distribution of speeds within each material. The fasted moving molecules in the water would have more kinetic energy than the slowest moving atoms in the metal.
28. a. The mechanical kinetic energy of the clay $\frac{1}{2}mv^2$ is mainly transformed into internal energy of the clay (its temperature would increase). It essentially becomes the increased random kinetic energy of the individual atoms in the clay. A small amount of energy would be transferred to the floor and ultimately the earth.
   b. Suppose you walk into a room and everything is on the floor – would you call it orderly or disorderly? "Pick up your room" is synonymous with getting it in order. In order for the clay to fall, it had to be elevated by something. To elevate it is to order it and arrange it. Also, the clay itself has a certain shape as it is falling, but after impact would be deformed and more randomized by "splatting". What is the "most random" shape for a lump of clay? A blob? Does the clay become more blob-like?
   c. If the clay spontaneously and magically launched upward from the floor with some mechanical kinetic energy $\frac{1}{2}mv^2$, by conservation of energy the clay and the floor below it would need to have a corresponding and equivalent decrease in internal energy. Because of the distribution of speeds of atoms in the materials, perhaps this could occur by a "random chance" series of collisions between individual atoms in the floor and clay all occurring at exactly the same time and resulting in force in exactly the same direction. But the odds of this are so vanishingly low as to be nonexistent.

29. a. As an ice cube is forming and heat is leaving it, the entropy of the water itself is decreasing, not increasing. Water in the form of an ice cube is more orderly and less random than a puddle. It *is* possible for entropy to decrease in some parts of the universe!
   b. But, by the 2nd Law of Thermodynamics, the decrease in entropy of the water that has been formed into an ice cube must be offset by a greater amount of increase in entropy of the environment surrounding the ice cube. While the cube is freezing inside the freezer, heat is being expelled into the room by the heat pump in the machine. This will cause the entropy of the room to increase more than the entropy of the ice cube decreased.
30. a. $\Delta S = -0.041$ J/K for the process in problem 25 going "right to left" (volume decrease)
   $\Delta S = +0.041$ J/K if the process is reversed going "left to right" (volume increase)
   b. Because the internal energy does not change if temperature is constant, heat added to the gas is equal to the work done by the gas. Extending the range of volume change would increase the amount of change in entropy.
   c. It is natural for a gas to spread out and expand. In this example, following an isothermal curve on the *PV* graph, the expansion of the gas is clearly an increase in entropy. The atoms being spread out farther apart is more disorderly than being compressed into a small volume. The gas has the same energy in either case, but if it is to actually be useful for something should it be "contained" (in a small volume) or allowed to "dissipate" (in a large volume)?