Physics 123 section 2 CID ___________

Homework 8

Score ________ / 30

1. A gasoline engine ignites the gasoline vapor inside of one of the cylinders, raising the temperature of the gas to a temperature of 1000 K and bringing the pressure up to 6.62×10^5 Pa. Then the piston expands adiabatically from a volume of 1 cm^3 to a volume of 3 cm^3. (a) What is the pressure after the expansion? (b) What is the temperature after the expansion? (c) What is the heat Q which enters the gas during the expansion? (d) What is the work done by the piston as it expands? (e) What is the change in the internal energy of the gas as it expands? Assume that the air molecules have 6 degrees of freedom which are active at the temperatures involved.

2. Consider the demonstration that Wayne Peterson did for us in class, where he put a piece of cotton inside of a cylinder and then compressed the gas in the cylinder with a piston, causing the air to heat up and igniting the cotton. Cotton burns in air when it reaches a temperature of 95 °C. (a) By what factor do we need to compress the volume of the air in order to get the cotton to ignite? (b) What is the pressure of the air in the cylinder when the air reaches the ignition temperature. Assume that $\gamma = 7/5$ for air, that the compression is perfectly adiabatic, that no air escapes around the piston, and that the air is at 25 °C and atmospheric pressure before the compression.

3. Six cars are moving in the same direction at different speeds on the highway. Their speeds are 45 MPH, 44 MPH, 68 MPH, 72 MPH, 78 MPH and 74 MPH. (a) What is their average speed? (b) What is their rms speed?

4. (a) Explain what v_{mp} represents. (b) If you were to measure the speed of every helium atom in one cubic meter of gaseous helium at room temperature and atmospheric pressure, about how many would be going exactly at v_{mp}? Assume that you can measure their speeds with infinite precision.

5. The escape speed for the Earth (the speed at which something on the surface of the Earth will have enough kinetic energy to break away from the pull of Earth's gravity) is 11,190 m/s. (a) At what temperature will the most probable velocity of molecules in a gas of nitrogen be greater than the Earth's escape velocity? (b) At what temperature will the most probable velocity of helium atoms be greater than the Earth's escape velocity? The mass of a nitrogen molecule is 4.653×10^{-26} kg and the mass of a helium atom is 6.6471×10^{-27} kg.

6. Lets "derive" the formula for the mean free path in a gas (the word "derive" is in quotations because we will use a bit of "hand-waving" along the way). The mean free path is the average distance a molecule in a gas travels before bumping into another molecule. Consider a volume V containing N molecules. For simplicity lets treat the molecules as if they were little hard spheres of diameter d. This means that if the center of two molecules gets within a distance d of each other, they collide. To simplify this problem, imagine that all of the molecules are standing still, with just one molecule moving through them. As it moves, it sweeps out a little cylinder of volume which has a diameter $2d$ and a length equal to the distance that the molecule has traveled. After it has traveled some distance, if the center of another molecule lies within that volume, a collision has occurred.

(a) To simplify matters even more, we will work in the reference frame of the moving molecule. In the reference frame of that molecule, it is standing still, and all of the other molecules are moving and sweeping out little tubes of volume. If any of those tubes touches the center of the "stationary" molecule, a collision has occurred. Now some more hand waving . . . If the molecules have moved so far such that all of the volume swept out by all of the molecules equals the total volume of the gas, it is very likely that our "stationary" molecule has collided with something. If the distance that the molecules move when this happens is called l, find an equation for l in terms of the density of particles $n_V = N/V$ and the diameter of the molecules d. This distance is known as the mean free path.

(b) It turns out that the mean free path is actually smaller than this by a factor of $\sqrt{2}$ because the other molecules aren't standing still, but are moving in random directions. Taking this into account, what is the correct formula for l? This is something you should remember — especially those of you with a 7th edition book, because it was taken out of the text.

(c) In a gas of nitrogen molecules at atmospheric pressure and at a temperature of 25 °C, what is the mean free path? Nitrogen molecules have a mass of 4.653×10^{-26} kg and a molecular "diameter" of about 3×10^{-10} m. Note that most of the air in the atmosphere is nitrogen, so this should give you an idea of what is happening in the air around you. The fact that it is so short explains why it takes so long for smells to travel from one side of the room to the other, even though the molecules themselves are traveling at very high speeds.

(d) If you divide the mean free path by the average velocity $\bar{v} = v_{avg}$ you find the average time between collisions. This number is often very important — for example, if you are doing a gas-phase chemical reaction, you need to know how often particles collide. How often, on average, do the particles in part (c) collide?

Extra problems I recommend you work (not to be turned in)

- (a) If I have a cylinder which is 20 cm long with a piston in one end, and then compress the gas and heat it up, how tall will the column of gas be when it has reached a temperature of 3422 °C — the melting point of tungsten, the metal with the highest melting point. (b) What will the pressure of the gas be? Assume that I start with the cylinder filled with air at 300 K at atmospheric pressure, and assume that $\gamma = 7/5$.

- In the lab we often use a unit of pressure called a Torr, where 768 Torr is equal to one atmosphere. Really good vacuum systems can get down to pressures of about 10^{-12} Torr. (a) At this pressure, how many molecules are there inside of a vacuum chamber with a volume of 1 m^3? (b) What is the mean free path for these molecules? (c) How often do they run into each other? Assume that the molecules are mostly nitrogen molecules at room temperature.