Homework for Week 3

Due Friday Oct 18 at 5pm

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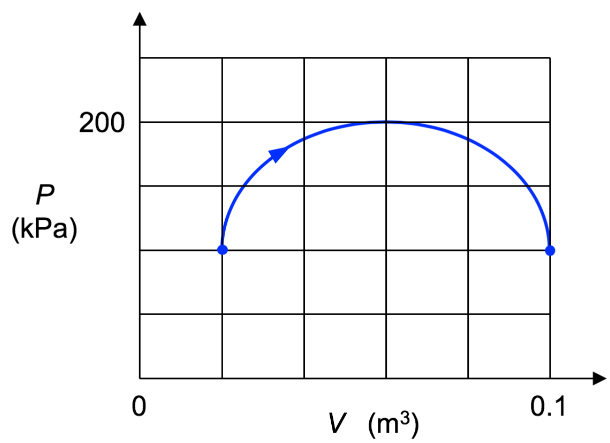
1. Integration techniques

You should be familiar with three techniques for calculating integrals

1. Equations and calculus
2. Geometric shapes (calculate a generalized area)
3. Simple numerical integration (a sum of y-values appropriately weighted by Δx)

For the following three questions, pick the most appropriate integration technique.

a) The blue curve on the PV diagram shows the pressure and volume of a gas over some period of time. The arrow indicates the direction from initial state to final state. Find the work energy going in (or out) of the gas to within ±5%. Remember the sign convention for work that we are using in this class. Check the sign and units of your answer.



b) Consider compression of a gas for which

$$P = (\text{constant}) \cdot V^{-5/3}.$$

The initial volume is 0.1 m^3 and the final volume is final volume is 0.05 m^3. The initial pressure is 100 kPa. Find the work done (use the standard sign convention). Check the sign and units of your answer.

c) The following pressure and volume data was measured inside a cylinder of a 1.6-liter 4-cylinder engine. During this time period, the number of gas molecules inside the cylinder was fixed. Calculate the work done during this time period (use the standard sign convention).

Time (ms)	P (kPa)	V (liters)
1	5000	0.05
2	3500	0.10
3	2500	0.15
4	1700	0.20
5	1100	0.25
6	600	0.30
7	400	0.35
8	300	0.40

2. Miscellaneous

a) T5B.8 Interstellar space has about one H_2 molecule per cubic centimeter. The temperature of deep space is about 3 K. What is the pressure of this interstellar gas? How does it compare to the best vacuum we can achieve in the laboratory (~ 10^{-13} Pa)?

b) T7B.12 Explain physically (no equations!) why a gas's temperature increases as we compress it adiabatically.

Note: The definition of adiabatic is that no heat crosses the boundary that encloses the gas.

Note: Look for an answer that uses the kinetic theory of gases. Kinetic theory is the idea that a gas consists of little particles that have kinetic energy. The average kinetic energy is proportional to the temperature. The particles whiz around and undergo elastic collisions with the walls of a container (Figure T5.4).

3. Two values of specific heat capacity (long-answer format)

If you google "specific heat capacity of air" you will find two values:

$$c_p = 1.00 \text{ kJ/kg.K, at } T = 293 \text{ K, } P = 1 \text{ atm}$$

$$c_v = 0.72 \text{ kJ/kg.K, at } T = 293 \text{ K, } P = 1 \text{ atm}$$

The first value, c_p, refers to the heat required to the raise the air temperature while holding pressure constant. The second value, c_v, refers to the heat required to raise air the air temperature while holding volume constant. The goal of this question is to compare these values to the physics we've learned so far. To simplify the question, treat the air as if it were pure nitrogen gas (the main component of air). Nitrogen gas has a density of 1.17 kg/m^3 at $T = 293$ K and atmospheric pressure. The equation of state is $PV = Nk_BT$. The internal energy of the gas is $(5/2)Nk_BT$.

a) On a PV diagram, mark the initial state of the nitrogen gas (assume 1 kg of gas at 1 atm). On this same diagram, show how the state of the gas would change if heat was added while (i) keeping volume constant or (ii) keeping pressure constant.

b) For the constant volume process, how much heat does it take to raise the temperature by 1 K?

c) For the constant pressure process, how much heat does it take to raise the temperature by 1 K?

Sense making: Compare your results to the values listed on google.

4. Degrees of freedom

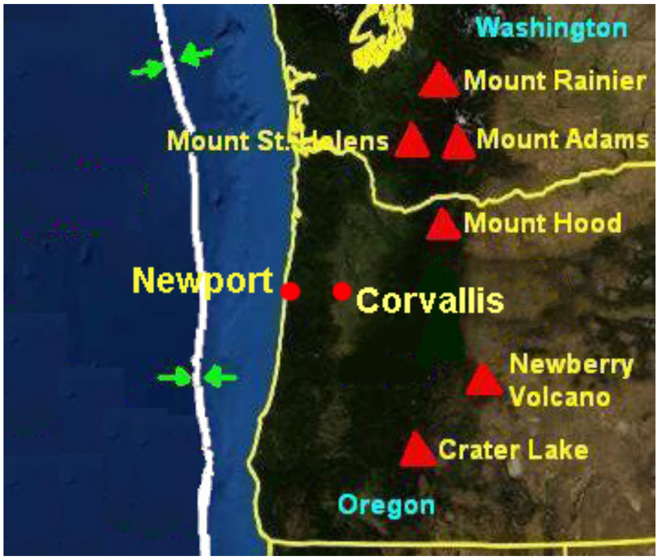
a) T5B.4 An atom of helium can store energy by bumping its electron from its lowest orbital energy level to a higher orbital energy level. In particular, moving an electron from the lowest state to the next-lowest state would store an energy of 24.6 eV. Explain why we can ignore this energy storage mode when calculating the heat capacity of helium gas at ordinary temperatures.

b) T5B.5 Calculate the approximate temperatures at which the following energy storage modes of a nitrogen molecule become "unfrozen" (i) The kinetic energy mode (energy quanta for this mode are about 10^{-7} eV). (ii) The rotational energy mode (energy quanta for this mode are about 0.00025 eV). (iii) The vibrational energy mode (energy quanta for this mode are about 0.29 eV).

Note: 1 eV = 1.6×10^{-19} J.

5. Seismic waves (long-answer format)

A typical earthquake produces two types of seismic waves. Primary seismic waves (p-waves) are longitudinal waves that move through the earth's upper crust with speed anywhere from 3 km/s to 5 km/s (the exact speed depends on the local composition of the earth's crust). Secondary waves (s-waves) are transverse waves that move slower than P waves. The S-wave speed is typically $^3/_5$ of the P-wave speed in any given material. The map below shows the Cascadia subduction zone (white line) just off the coast of Oregon. In the next 50 years, there is a 30% chance that a very large earthquake will occur with an epicenter on this white line.



a) Assume there is an earthquake centered on the Cascadia subduction zone directly west of Corvallis. **Estimate** the time delay between the arrival of P waves and the arrival of S waves in Corvallis. Give a range of possible time delays.

> *Sense making*: Is the time delay between p-wave arrival and s-wave arrival long enough for our class to evacuate Weniger Hall? (s-waves are more destructive than p-waves).

b) Rather than rely on p-waves as a warning system, what about using standard telecommunication technology? Imagine there was a p-wave sensor in Newport that "instantly" sent a warning to Corvallis (signals can't go faster than the speed of light). Estimate the time delay between triggering the Newport p-wave sensor and the arrival of s-waves in Corvallis.