1. גז אידאלי עם יחס קיבולי החום γ=1.5 מתכווץ באופן אדיאבטי עד שלחץ יעלה פי 10. אחר כך הוא מתפשט באופן איזותרמי עד שהנפח חוזר לערך התחלתי. פי כמה בערך גדול הלחץ הסופי מהלחץ ההתחלתי?

Adiabatic compression: $p_0V_0^\gamma = p_1V_1^\gamma;\quad p_1 = 10p_0 \quad\Rightarrow\quad V_0 = 10^{1/\gamma}V_1$

Isothermal expansion: $p_1V_1 = p_2V_2;\quad V_2 = V_0$

$$p_2 = \frac{V_1}{V_0}p_1 = \frac{1}{10^{1/\gamma}}10p_0 = 10^{1-1/\gamma}p_0 = 10^{1/3}p_0 \approx 2p_0$$

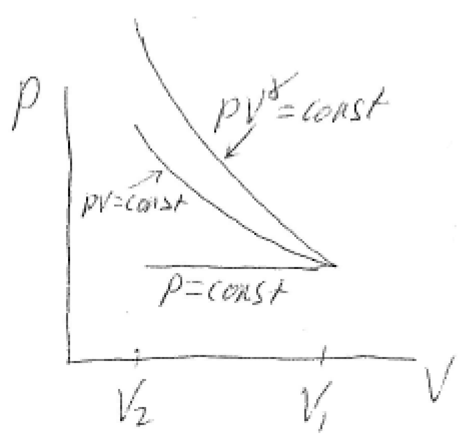
2. גז אידאלי מתכווץ באופן אדיאבטי, איזותרמי ואיזובארי מאותו מצב. באיזה מתהליכים האלו בוצעה העבודה המרבית ובאיזו הקטנה ביותר?

For an isobaric process, *p=const;*

isothermal process *pV=const;*

adiabatic process *pV*$^\gamma$*=const,* where $\gamma = \frac{c_p}{c_V} = \frac{c_V + R}{c_V} > 1$

The work $\int pdV$ may be conveniently presented as the area under the graph of the process in *(pV)* plane:



One sees that the maximal work is performed in the course of the adiabatic process whereas the minimal work in the course of the isobaric process.

3. אלומת מולקולות מימן עם צפיפות $n=10^{20}$ cm^{-3} ומהירות v= 400 m/s פוגע בקיר בזווית $\alpha=60^o$ לנורמל. מצא\י את הלחץ על הקיר בהנחה שהתנגשויות הן אלסטיות.

$$\mathrm{v}_{\mathrm{normal}} = \mathrm{v}\cos\alpha = \tfrac{1}{2}\mathrm{v}$$
$$\Delta p = 2m\mathrm{v}_{\mathrm{normal}} = m\mathrm{v}; \quad m = 2m_p$$

The number of collisions with the surface *S* during the time *dt* is $dN = Sn\mathrm{v}_{\mathrm{normal}}dt$

The transferred momentum is $\Delta p dN = 2m\mathrm{v}\cdot Sn\mathrm{v}_{\mathrm{normal}}dt = m_p\mathrm{v}^2nSdt$. Now the pressure is found as

$$P = \frac{1}{S}\frac{dp}{dt} = m_p\mathrm{v}^2n = \frac{\left(4\cdot10^4\right)^2\cdot10^{20}}{6\cdot10^{23}} \approx 2.7\cdot10^5\,\mathrm{dyne/cm^2} = 2.7\cdot10^4\,\mathrm{Pa}$$

4. **The radiation could be considered as photon gas. Photons are particles moving with the velocity of light, *c*, their energy, *e*, and momentum, p, being related as *e=pc.* a) Consider a photon beam incident perpendicularly on a reflecting wall and show that the pressure exerted by the beam on the wall is *P=2ne,* where *n* is the photon density in the incident beam. Note that this expression could also be presented as *P=*ε, where ε*=2ne* is the radiation energy density (taking into account both incident and reflected radiation). b) Generalize the previous result to the case of a photon beam incident on a reflecting wall at an angle θ. c) Show that if the radiation is isotropic, the pressure on the wall is *P=*ε*/3.***

$$\Delta p = 2p = 2\frac{e}{c}; \quad dN = ncSdt$$

a) $$P = \frac{F}{S} = \frac{1}{S}\frac{dp}{dt} = \frac{1}{s}\Delta p\frac{dN}{dt} = 2en = \varepsilon$$

b) $$\Delta p = 2p\cos\theta; \quad dN = nc\cos\theta Sdt$$

$$P = \frac{1}{S}\frac{dp}{dt} = 2en\cos^2\theta = \varepsilon\cos^2\theta;$$

c)

$$\overline{\cos^2\theta} = \frac{1}{2\pi}\int_{\text{half sphere}} \cos^2\theta d\Omega = \int_0^{\pi/2} \cos^2\theta \sin\theta d\theta = \frac{1}{3}$$

$$P = \frac{1}{3}\varepsilon$$

5. **In a helium and nitrogen mixture, the fraction of helium by mass being 80%. a) Find the molecular weight of the mixture. b) Find the molar heat capacity at constant volume of the mixture. c) Find the adiabatic index of the mixture. Helium is monoatomic; nitrogen is diatomic, the molecules could be considered as rigid.**

a) The mass of the hydrogen molecule is $2m_p$, helium $4m_p$. Therefore the number densities of the molecules are related as

$$\frac{4m_p n_{\text{He}}}{2m_p n_{\text{H}}} = 4; \qquad \frac{n_{\text{He}}}{n_{\text{H}}} = 2$$

The molecular weight is the average mass of the molecule in units of the proton mass

$$m = \frac{2n_{\text{H}} + 4n_{\text{He}}}{n_{\text{H}} + n_{\text{He}}} = \frac{2 + 4\times 2}{3} = 3.3$$

b) The heat capacity per a molecule is (5/2)k and (3/2)k, correspondingly. The number of the two types of molecules in one mole of the mixture is

$$N_H = \frac{N_A}{3}; \quad N_{\text{He}} = \frac{2N_A}{3}.$$

Therefore the molar heat capacity is

$$C_V = \frac{5}{2}kN_{\text{H}} + \frac{3}{2}kN_{\text{He}} = \left(\frac{5}{2}\frac{1}{3} + \frac{3}{2}\frac{2}{3}\right)kN_A = 1.9R = 16 \text{ J/mole K} = 4 \text{ cal/mole K}$$

c) $$g = \frac{C_p}{C_V} = \frac{C_V + R}{C_V} = 1 + \frac{1}{1.9} = 1.5$$

6. **Making use of the Dulong-Petit law, find the specific heat capacity (per unit mass) of salt (NaCl).**

In ionic crystals, each atom contributes 3k to the heat capacity. The atomic masses of Na and Cl are 23 and 35.5, correspondingly. Therefore the total number of atoms in a gram of salt is $\frac{2}{(23+35.5)m_p}$. Now the specific heat capacity is

$$c = \frac{2 \cdot 3k}{58.5 m_p} = 0.1 \cdot 1.4 \cdot 10^{-16} \cdot 6 \cdot 10^{23} = 8.3 \cdot 10^{6}$$ erg/g K=0.83 J/g K=0.2 cal/g K