20. JEDNADŽBA STANJA PLINA (3.99. - 3.121.)

3.99. Vodik određene mase zauzima obujam 20,0 cm^3 pri 5 ^0C i normiranom tlaku. Odredi njegov obujam pri 30 ^0C uz tlak $1,07 \cdot 10^5$ Pa.

$V_1 = 20\ cm^3 = 2 \cdot 10^{-5}\ [m^3]$
$t_1 = 5\ ^0C = 278\ [K]$
$p_1 = 101300\ [Pa]$
$t_2 = 30\ ^0C = 303\ [K]$
$p_2 = 1,07 \cdot 10^5\ [Pa]$
$V_2 = ?$

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

$$V_2 = \frac{p_1 \cdot V_1 \cdot T_2}{T_1 \cdot p_2} = \frac{1,013 \cdot 10^5 \cdot 2 \cdot 10^{-5} \cdot 303}{278 \cdot 1,07 \cdot 10^5} = 2,06 \cdot 10^{-5}\left[m^3\right] = 20,6\left[cm^3\right]$$

3.100. Gumena lopta sadrži pri 20 ^0C dvije litre zraka uz atmosferski tlak $1,07 \cdot 10^5$ Pa. Kakav će obujam poprimiti zrak u lopti ako je spustimo u vodu na dubinu 10 m? Temperatura vode je 4 ^0C.

$t_1 = 20\ ^0C = 293\ [K]$
$V_1 = 2\ [l] = 2 \cdot 10^{-3}\ [m^3]$
$p_1 = 1,07 \cdot 10^5\ [Pa]$
$h = 10\ [m]$
$t_2 = 4\ ^0C = 277\ [K]$
$V_2 = ?$

$$p_2 = p_1 + \rho \cdot g \cdot h = 1,07 \cdot 10^5 + 1000 \cdot 9,81 \cdot 10 = 2,051 \cdot 10^5\left[Pa\right]$$

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

$$V_2 = \frac{p_1 \cdot V_1 \cdot T_2}{T_1 \cdot p_2} = \frac{1,07 \cdot 10^5 \cdot 2 \cdot 10^{-5} \cdot 277}{293 \cdot 2,051 \cdot 10^5} = 9,86 \cdot 10^{-4}\left[m^3\right] = 0,986\left[l\right]$$

3.101. Gustoća dušika u normiranim uvjetima iznosi 1,25 kg/m^3. Odredi gustoću dušika pri 42 ^0C i $9,7 \cdot 10^4$ Pa.

$\rho_1 = 1,25\ [kg/\ m^3]$
$t_1 = 273\ [K]$
$p_1 = 1,013 \cdot 10^5\ [Pa]$
$t_2 = 42\ ^0C = 315\ [K]$
$p_2 = 9,7 \cdot 10^4\ [Pa]$
$\rho_2 = ?$

$$V_1 = \frac{m}{\rho_1}$$

$$V_2 = \frac{m}{\rho_2}$$

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

$$V_2 = \frac{p_1 \cdot V_1 \cdot T_2}{T_1 \cdot p_2}$$

$$\frac{m}{\rho_2} = \frac{p_1 \cdot \frac{m}{\rho_1} \cdot T_2}{T_1 \cdot p_2}$$

$$\frac{m}{\rho_2} = \frac{p_1 \cdot m \cdot T_2}{\rho_1 \cdot T_1 \cdot p_2} \Rightarrow \rho_2 = \frac{\rho_1 \cdot T_1 \cdot p_2}{p_1 \cdot T_2}$$

$$\rho_2 = \frac{1,25 \cdot 273 \cdot 9,7 \cdot 10^4}{1,013 \cdot 10^5 \cdot 315} = 1,0373\left[\frac{kg}{m^3}\right]$$

3.102. Balon od 20 l napunjen je kisikom koji je pri 16 ^0C pod tlakom $1,013 \cdot 10^7$ Pa. Koliki je normirani obujam?

$V_1 = 20\ [l] = 20 \cdot 10^{-3}\ [m^3] = 0,02\ [m^3]$
$t_1 = 16\ ^0C = 289\ [K]$
$p_1 = 1,013 \cdot 10^7\ [Pa]$
$t_2 = 273\ [K]$
$p_2 = 1,013 \cdot 10^5\ [Pa]$
$V_2 = ?$

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

$$V_2 = \frac{p_1 \cdot V_1 \cdot T_2}{T_1 \cdot p_2} = \frac{1,013 \cdot 10^7 \cdot 0,02 \cdot 273}{289 \cdot 1,013 \cdot 10^5} = 1,889\left[m^3\right] = 1889\left[l\right]$$

3.103. Pri temperaturi zraka 17 ^{0}C i normiranome atmosferskom tlaku uronimo staklenu cijev u posudu sa živom. U staklenoj se cijevi nalazi stanovita količina zraka tako da je razina žive u cijevi 5 cm iznad razine žive u posudi. Duljina dijela cijevi koji je ispunjen zrakom iznosi 50 cm. Za koliko se mora povisiti temperatura okolnog zraka da se živa u cijevi spusti do razine žive u posudi?

$t_1 = 17\ ^0C = 290$ [K]
$p_1 = (76 - 5)$ cm Hg = 71 cm Hg
$p_2 = p_a = 76$ cm Hg
$h = 5$ [cm]
$h_1 = 50$ [cm]
$\Delta T = ?$

$$V_1 = A \cdot h_1 = A \cdot 50$$
$$V_2 = A \cdot h_2 = A \cdot (h + h_1) = A \cdot 55$$

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$
$$T_2 = \frac{p_2 \cdot V_2 \cdot T_1}{p_1 \cdot V_1}$$
$$T_2 = \frac{76 \cdot A \cdot 55 \cdot 290}{71 \cdot A \cdot 50} = 341{,}46[K]$$
$$\Delta T = 341{,}46 - 290 = 51{,}47[K]$$

3.104. Neki plin mase 12 g ima pri 7 ^{0}C obujam $4 \cdot 10^{-3}$ m^3. Nakon zagrijavanja plina pri stalnom tlaku gustoća plina je $6 \cdot 10^4$ g/cm^3. Do koje je temperature ugrijan plin?

$V_1 = 4 \cdot 10^{-3}$ [m^3]
$m = 12$ [g] = 0,012 [kg]
$t_1 = 7\ ^0C = 280$ [K]
$p = konst$
$\rho_2 = 6 \cdot 10^{-4}$ [g/cm^3] = 0,6 [kg/m^3]
$t_2 = ?$

$$V_2 = \frac{m}{\rho_2}$$
$$V_2 = \frac{0{,}012}{0{,}6}$$
$$V_2 = 0{,}02[m^3]$$

$$p = konst$$
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$T_2 = \frac{V_2 \cdot T_1}{V_1} = \frac{0{,}02 \cdot 280}{4 \cdot 10^{-3}}$$
$$T_2 = 1400[K] = 1127[^0C]$$

3.105. Gustoća je kisika pri 0 ^{0}C i normiranom tlaku 1,43 g/l. Nađi gustoću kisika pri 17 ^{0}C i tlaku $9{,}3 \cdot 10^4$ Pa.

$\rho_1 = 1{,}43$ [g/l] = 1,43 [kg/m^3]
$t_1 = 0\ ^0C = 273$ [K]
$p_1 = 1{,}013 \cdot 10^5$ [Pa]
$t_2 = 17\ ^0C = 290$ [K]
$p_2 = 9{,}3 \cdot 10^4$ [Pa]
$\rho_2 = ?$

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$
$$\frac{p_1 \cdot \frac{m}{\rho_1}}{T_1} = \frac{p_2 \cdot \frac{m}{\rho_2}}{T_2}$$
$$\frac{p_1}{\rho_1 \cdot T_1} = \frac{p_2}{\rho_2 \cdot T_2}$$

$$\rho_2 = \frac{p_2 \cdot \rho_1 \cdot T_1}{p_1 \cdot T_2}$$
$$\rho_2 = \frac{9{,}3 \cdot 10^4 \cdot 1{,}43 \cdot 273}{1{,}013 \cdot 10^5 \cdot 290}$$
$$\rho_2 = 1{,}235\left[\frac{kg}{m^3}\right]$$

3.106. Kolika je masa dušika koji pri 25 ^{0}C u obujmu 100 litara tlači $1{,}08 \cdot 10^5$ Pa?

$M(N_2) = 28{,}02 \cdot 10^{-3}$ [kg]
$t = 25$ [^{0}C] = 298 [K]
$V = 100$ [l] = 0,1 [m^3]
$p = 1{,}08 \cdot 10^5$ [Pa]
$m = ?$

$$p \cdot V = n \cdot R \cdot T$$
$$p \cdot V = \frac{m}{M} \cdot R \cdot T$$
$$m = \frac{p \cdot V \cdot M}{R \cdot T} = \frac{1{,}08 \cdot 10^5 \cdot 0{,}1 \cdot 28{,}02 \cdot 10^{-3}}{8{,}314 \cdot 298} = 0{,}122[kg]$$

3.107. Pri 0 ^{0}C i normiranom tlaku u posudi određenog obujma nalazi se 2,35 g plina neona. Kolika masa tog plina može ispuniti posudu pri 100 ^{0}C i tlaku 10,13 · 10^5 Pa?

$t_1 = 0\ ^0C = 273$ [K]
$p_1 = 1{,}013 \cdot 10^5$ [Pa]
$m_{neona} = 2{,}35$ [g] = 0,00235 [kg]
$t_2 = 100\ ^0C = 373$ [K]
$p_2 = 10{,}13 \cdot 10^5$ [Pa]
$m_2 = ?$

$$p_1 \cdot V_1 = n \cdot R \cdot T_1$$
$$p_1 \cdot V_1 = \frac{m}{M} \cdot R \cdot T_1$$
$$V_1 = \frac{m \cdot R \cdot T_1}{M \cdot p_1}$$
$$V_1 = \frac{0{,}00235 \cdot 8{,}314 \cdot 273}{20{,}18 \cdot 10^{-3} \cdot 1{,}013 \cdot 10^5}$$
$$V_1 = 0{,}0026 \left[m^3\right]$$
$$\rho_1 = \frac{m}{V_1} = \frac{0{,}00235}{0{,}0026}$$
$$\rho_1 = 0{,}9 \left[\frac{kg}{m^3}\right]$$

$$\rho_2 = \frac{p_2 \cdot \rho_1}{p_1 \cdot (1 + \alpha \cdot t_2)}$$
$$\rho_2 = \frac{10{,}13 \cdot 10^5 \cdot 0{,}9}{1{,}013 \cdot 10^5 \cdot (1 + \frac{1}{273{,}15} \cdot 100)}$$
$$\rho_2 = 6{,}58 \left[\frac{kg}{m^3}\right]$$

$$m_2 = \rho_2 \cdot V_2$$
$$m_2 = 6{,}58 \cdot 0{,}0026$$
$$m_2 = 0{,}0171 \left[kg\right]$$

3.108. Čelična boca obujma 5000 cm^3 sadrži kisik u normiranim uvjetima. Koliko grama kisika moramo dodati u bocu da tlak povećamo na 40,5 · 10^5 Pa uz nepromijenjenu temperaturu?

$V = 5000$ [cm^3] = 5 · 10^{-3} [m^3]
$p_1 = 1{,}013 \cdot 10^5$ [Pa]
$T_1 = 273$ [K], t = konst
$p_2 = 40{,}5 \cdot 10^5$ [Pa]
$\Delta m = ?$

$$p_1 \cdot V = n \cdot R \cdot T$$
$$p \cdot V = \frac{m}{M} \cdot R \cdot T$$
$$m = \frac{p \cdot V \cdot M}{R \cdot T}$$
$$m = \frac{1{,}013 \cdot 10^5 \cdot 5 \cdot 10^{-3} \cdot 32 \cdot 10^{-3}}{8{,}314 \cdot 273}$$
$$m = 0{,}00714 \left[kg\right]$$

$$p_2 \cdot V = k_B \cdot N \cdot T$$
$$N = \frac{p_2 \cdot V}{k_B \cdot T}$$
$$N = \frac{40{,}5 \cdot 10^5 \cdot 5 \cdot 10^{-3}}{1{,}38 \cdot 10^{-23} \cdot 273}$$
$$N = 5{,}375 \cdot 10^{24}\, molekula$$

$$N = n \cdot N_A$$
$$n = \frac{N}{N_A} = \frac{5{,}375 \cdot 10^{24}}{6{,}022 \cdot 10^{23}} = 8{,}925 \text{ mola}$$
$$m = n \cdot M = 8{,}925 \cdot 32 \cdot 10^{-3} = 0{,}2865 \left[kg\right]$$
$$\Delta m = 0{,}2865 - 0{,}00714 = 0{,}27847 \left[kg\right]$$

3.109. Iz elektronske cijevi isisan je plin do tlaka 1,59 · 10^{-3} Pa pri 27 ^{0}C. obujam cijevi je 100 cm^3. Koliko je molekula preostalo u cijevi?

$p = 1{,}59 \cdot 10^{-3}$ [Pa]
$t = 27\ [^0C] = 300$ [K]
$V = 100$ [cm^3] = 10^{-4} [m^3]
$N = ?$

$$N = \frac{p \cdot V}{k_B \cdot T}$$
$$N = \frac{1{,}59 \cdot 10^{-3} \cdot 10^{-4}}{1{,}38 \cdot 10^{-23} \cdot 300}$$
$$N = 3{,}84 \cdot 10^{13}\, molekula$$

3.110. Smjesa plinova sadrži pri normiranom tlaku 65,0% dušika, 15,0% kisika i 20,0% ugljičnog dioksida. Koliki je parcijalni tlak svakog plina?

$p_1 = 1{,}013 \cdot 10^5$ [Pa]
$N_2 \rightarrow 65\%$
$O_2 \rightarrow 15\%$
$CO_2 \rightarrow 20\%$

$$p(N_2) = 0{,}65 \cdot 101300 = 65845[Pa]$$
$$p(O_2) = 0{,}15 \cdot 101300 = 15195[Pa]$$
$$p(CO_2) = 0{,}2 \cdot 101300 = 20620[Pa]$$

3.111. U zatvorenoj posudi obujma 1 m3 nalazi se 0,5 kg vode i 1,6 kg kisika. Odredi tlak u posudi pri 500 ^{0}C ako znamo da pri toj temperaturi sva voda prijeđe u paru.

$V = 1$ [m^3]
$m(H_2O) = 0{,}5$ [kg]
$m(O_2) = 1{,}6$ [kg]
$t = 500\ ^0C = 773$ [K]
$p = ?$

kisik:

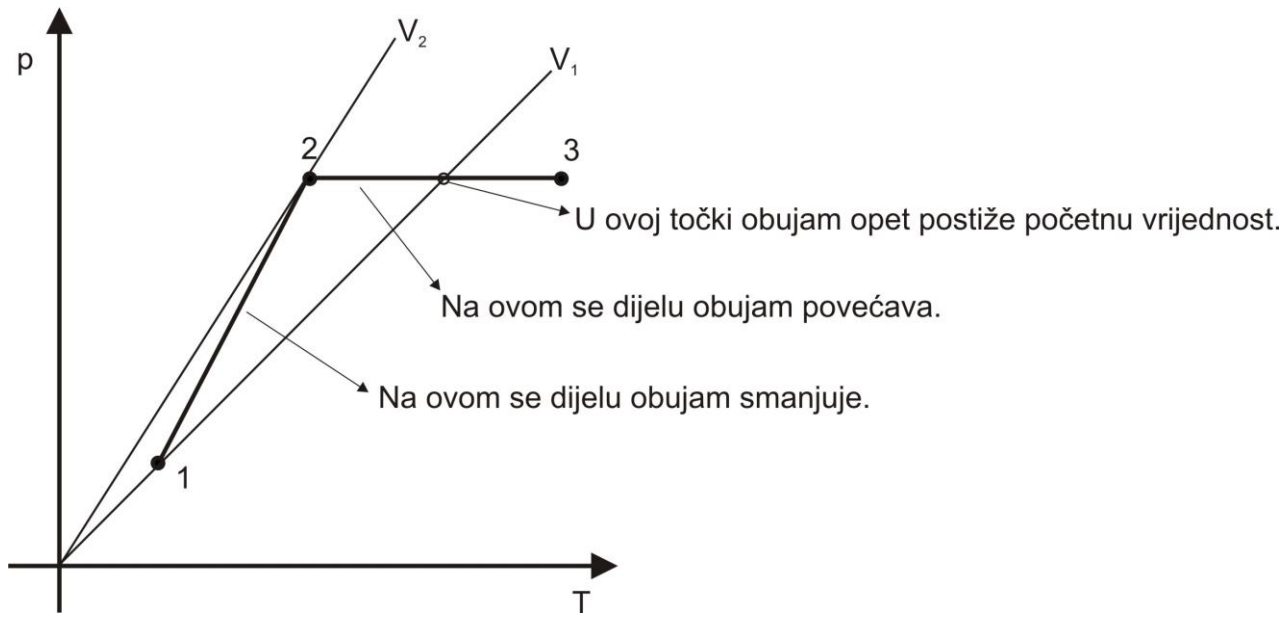
$$p_1 \cdot V = n \cdot R \cdot T$$
$$p_1 = \frac{n \cdot R \cdot T}{V}$$
$$p_1 = \frac{m \cdot R \cdot T}{M \cdot V}$$
$$p_1 = \frac{1{,}6 \cdot 8{,}314 \cdot 773}{32 \cdot 10^{-3} \cdot 1}$$
$$p_1 = 3{,}213 \cdot 10^5 [Pa]$$

vodena para:

$$p_2 \cdot V = n \cdot R \cdot T$$
$$p_2 = \frac{n \cdot R \cdot T}{V}$$
$$p_2 = \frac{m \cdot R \cdot T}{M \cdot V}$$
$$p_2 = \frac{0{,}5 \cdot 8{,}314 \cdot 773}{18 \cdot 10^{-3} \cdot 1}$$
$$p_1 = 1{,}785 \cdot 10^5 [Pa]$$

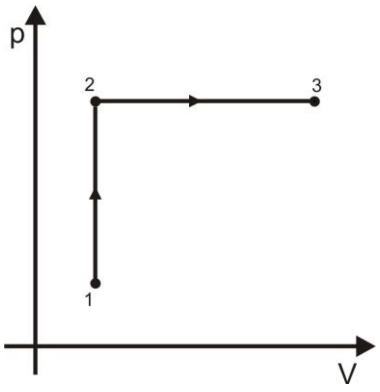
$$p = p_1 + p_2$$
$$p = 3{,}213 \cdot 10^5 + 1{,}785 \cdot 10^5$$
$$p = 4{,}998 \cdot 10^5 [Pa]$$

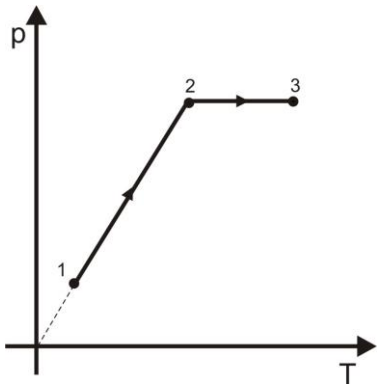
3.112. Na slici grafički je prikazana ovisnost tlaka plina o temperaturi. Odredi kako se mijenja obujam plina pri prijelazu iz stanja 1 u stanje 3.

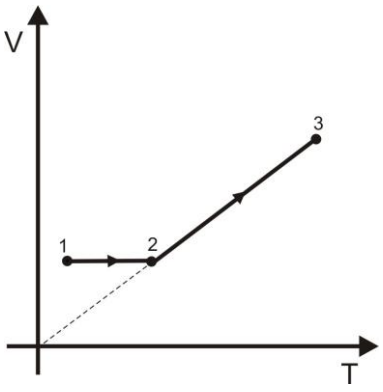


3.113. Nekom plinu promijenilo se stanje prema grafikonu na prvoj slici. Nacrtaj grafikon tog procesa u koordinatnim sustavima *p,T* i *V,T*.

p,T
V,T

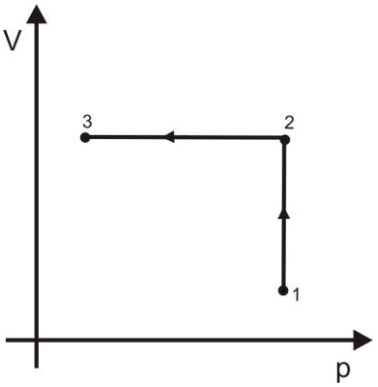






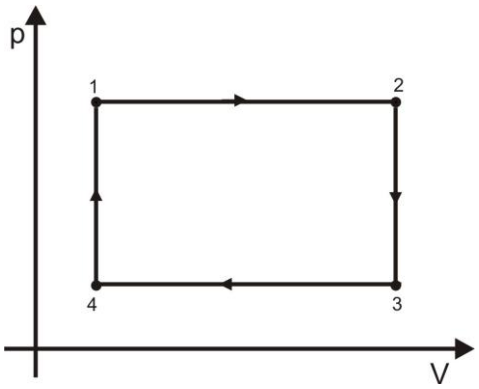
3.114. Stanje nekog plina prikazano je jednom točkom u koordinatnom sustavu V,p. Nacrtaj grafički prikaz promjene stanja plina ako plin najprije zagrijavamo pri stalnom tlaku, a zatim ga ohlađujemo pri stalnom obujmu.

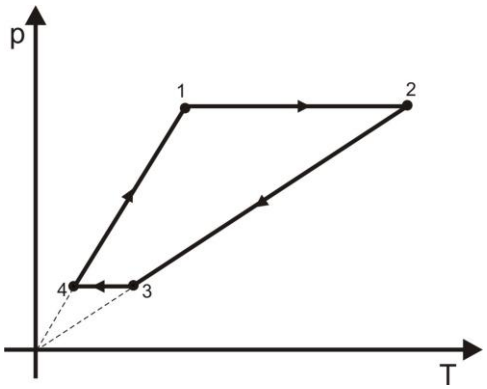
1 → 2 izobarno zagrijavanje
2 → 3 izohorno hlađenje



3.115. Na prvoj slici prikazan je grafikon promjene stanja idealnog plina u koordinatnom sustavu *p,V*. Prikaži taj kružni proces u koordinatnom sustavu *p,T*.

p,V u p,T





3.116. Kolika je kinetička energija translatornoga gibanja ($N \cdot \overline{E}_K$) molekula amonijaka (NH_3) mase 10 g pri 20 ^{0}C?

m(NH_3) = 10 g = 0,01 [kg]
t = 20 ^{0}C = 293 [K]
$\overline{E}_k = ?$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot n \cdot R \cdot T$$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot \frac{m}{M} \cdot R \cdot T = \frac{3}{2} \cdot \frac{0{,}01}{17 \cdot 10^{-3}} \cdot 8{,}314 \cdot 293 = 2149{,}4\left[J\right]$$

3.117. Odredi masu plina i srednju kinetičku energiju molekule helija koji se pri 30 ^{0}C nalazi u boci od 100000 litara pod tlakom 1,013 · 10^5 Pa.

t = 30 ^{0}C = 303 [K]
V_{helija} = 100000 [l] = 100 m^3
p = 1,013 · 10^5 [Pa]
m = ?
$\overline{E}_k = ?$

$$p \cdot V = n \cdot R \cdot T$$

$$p \cdot V = \frac{m \cdot R \cdot T}{M}$$

$$m = \frac{p \cdot V \cdot M}{R \cdot T}$$

$$m = \frac{1{,}013 \cdot 10^5 \cdot 100 \cdot 4 \cdot 10^{-3}}{8{,}314 \cdot 303}$$

$$m = 16{,}08\left[kg\right]$$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot n \cdot R \cdot T$$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot \frac{m}{M} \cdot R \cdot T$$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot \frac{16{,}08}{4 \cdot 10^{-3}} \cdot 8{,}314 \cdot 303$$

$$N \cdot \overline{E}_K = 1{,}519 \cdot 10^7\left[J\right]$$

3.118. Nađi srednju kvadratnu brzinu molekula vodika pri 0 ^{0}C i 100 ^{0}C ako je poznata masa molekule vodika m = 3,4 · 10^{-27} kg.

t_1 = 0 ^{0}C = 273 K
t_2 = 100 ^{0}C = 373 K
m_{vodika} = 3,4 · 10^{-27} [kg]
$\overline{v}_1 = ?$ $\overline{v}_2 = ?$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot n \cdot R \cdot T$$

$$n \cdot N_A \cdot \overline{E}_K = \frac{3}{2} \cdot n \cdot R \cdot T$$

$$N_A \cdot \overline{E}_K = \frac{3}{2} \cdot R \cdot T$$

$$N_A \cdot \frac{m \cdot v^2}{2} = \frac{3}{2} \cdot R \cdot T$$

$$v^2 = \frac{3 \cdot R \cdot T}{N_A \cdot m}$$

$$v_1 = \sqrt{\frac{3 \cdot 8{,}314 \cdot 273}{6{,}022 \cdot 10^{23} \cdot 3{,}4 \cdot 10^{-27}}} = 1823{,}6\left[\frac{m}{s}\right]$$

$$v_2 = \sqrt{\frac{3 \cdot 8{,}314 \cdot 373}{6{,}022 \cdot 10^{23} \cdot 3{,}4 \cdot 10^{-27}}} = 2131{,}6\left[\frac{m}{s}\right]$$

3.119. Izračunaj srednju kinetičku energiju gibanja molekula koje se nalaze u 1m^3 kisika uz normirane uvjete.

V_{kisika} = 1 [m^3]
p = 101300 [Pa]
T = 273 [K]
$\overline{E}_k = ?$

$$p \cdot V = n \cdot R \cdot T$$

$$n = \frac{p \cdot V}{R \cdot T}$$

$$n = \frac{101300 \cdot 1}{8{,}314 \cdot 273}$$

$$n = 44{,}63 \text{ mola}$$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot n \cdot R \cdot T$$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot 44{,}63 \cdot 8{,}314 \cdot 273$$

$$N \cdot \overline{E}_K = 151950\left[J\right]$$

3.120. Kolika je srednja kinetička energija molekula plina pri temperaturi 1200 K?

T = 1200 [K]
$\overline{E}_k = ?$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot n \cdot R \cdot T$$

$$N \cdot \overline{E}_K = \frac{3}{2} \cdot \frac{N}{N_A} \cdot R \cdot T$$

$$\overline{E}_K = \frac{3}{2} \cdot \frac{R \cdot T}{N_A}$$

$$\overline{E}_K = \frac{3}{2} \cdot \frac{8{,}314 \cdot 1200}{6{,}022 \cdot 10^{23}} = 2{,}48 \cdot 10^{-20} \left[J \right]$$

3.121. U balonu se nalazi 5 kg plina argona temperature 300 K. Kolika je unutrašnja energija tog plina?

m_{argona} = 5 [kg]
T = 300 [K]
U = ?

$$U = N \cdot \overline{E}_K = \frac{3}{2} \cdot n \cdot R \cdot T = \frac{3}{2} \cdot \frac{m}{M} \cdot R \cdot T$$

$$U = \frac{3}{2} \cdot \frac{5}{39{,}95 \cdot 10^{-3}} \cdot 8{,}314 \cdot 300$$

$$U = 4{,}68 \cdot 10^{5} \left[J \right]$$