Q1.

A transverse sinusoidal wave propagating along a stretched string is described by the following equation: *y (x,t)* = 0.350 sin [1.25*x* + 99.6*t*], where *x* and *y* are in meters, and *t* is in seconds. Consider the element of the string at *x* = 0. What is the time interval between the first two instants when this element has a displacement of *y* = + 0.175 m?

A) 21.0 ms
B) 63.1 ms
C) 31.5 ms
D) 45.2 ms
E) 73.1 ms

Ans:

$$y = 0.35 \cdot \sin(99.6\,t) = 0.35\sin\phi$$

$$\phi = \sin^{-1}\left(\frac{0.175}{0.350}\right) = 0.5 \Rightarrow \phi = \frac{\pi}{6}, \frac{5\pi}{6}, \ldots$$

$$\Rightarrow 99.6\,t = \frac{\pi}{6}, \frac{5\pi}{6}, \ldots \quad \Rightarrow t = 5.257, 26.285, \ldots \text{ms}$$

$$\Rightarrow \Delta t = 26.285 - 5.257 = 21.0 \text{ ms}$$

Q2.

A transverse sinusoidal wave travels on a stretched string and carries an average power of 0.470 W. If the wavelength of the wave is doubled while the tension and amplitude are not changed, what then is the average power carried by the wave?

A) 0.118 W
B) 0.235 W
C) 0.940 W
D) 1.88 W
E) 0.470 W

Ans:

$$P_{avg} = \frac{1}{2}\mu v \omega^2 y_m^2$$

$$v = \lambda f \Rightarrow f = \frac{v}{\lambda} \Rightarrow \frac{\omega}{2\pi} = \frac{v}{\lambda} \Rightarrow \omega = \frac{2\pi v}{\lambda}$$

$$\therefore P_{avg} = \frac{1}{2}\mu v \cdot \frac{4\pi^2 v^2}{\lambda^2} y_m^2 = \frac{2\pi^2 \mu v^3 y_m^2}{\lambda^2}$$

$\therefore P_{avg}$ is reduced by a factor of 4

$$\therefore P_{avg} = \frac{0.470}{4} = 0.118 \text{ W}$$

Q3.

A standing wave is set up on a string fixed at both ends. The waves on the string have a speed of 192 m/s and a frequency of 240 Hz. The amplitude of the standing wave at an antinode is 0.400 cm. Calculate the amplitude at a point on the string that is a distance of 30.0 cm from one end.

A) 0.283 cm
B) 0.200 cm
C) 0.405 cm
D) 0.605 cm
E) 0.354 cm

Ans:

$$\text{amplitude} = 2y_m \cdot \sin kx$$

$$= (0.400) \cdot \sin(7.85 \times 0.3)$$

$$= 0.283 \text{ cm}$$

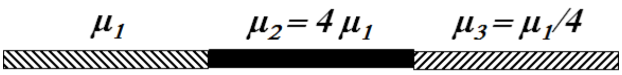
$$v = \lambda f = \frac{2\pi f}{k}$$

$$k = \frac{2\pi f}{v} = 7.85 \text{m}^{-1}$$

Q4.

Three pieces of string, each of length L, are joined together end to end as shown in **Figure 2**, to make a combined string of length $3L$. If the combined string is under tension τ, and it takes a transverse pulse time t_1 to travel the first piece, how much time does it take the pulse to travel the entire length $3L$?

Figure 2



A) $3.5\ t_1$
B) $2.5\ t_1$
C) $1.5\ t_1$
D) $4.5\ t_1$
E) $5.5\ t_1$

Ans:

$$t_1 = \frac{L}{v_1} = L \cdot \sqrt{\frac{\mu_1}{\tau}}$$

$$t_2 = \frac{L}{v_2} = L \cdot \sqrt{\frac{\mu_2}{\tau}} = 2L\sqrt{\frac{\mu_1}{\tau}} = 2t_1$$

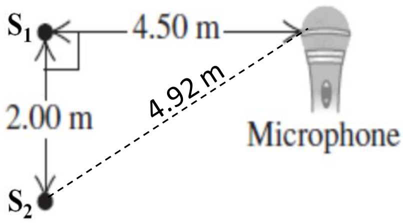
$$t_3 = \frac{L}{v_3} = L \cdot \sqrt{\frac{\mu_3}{\tau}} = \frac{L}{2}\sqrt{\frac{\mu_1}{\tau}} = \frac{t_1}{2}$$

$$\therefore \text{time} = t_1 + t_2 + t_3 = t_1 + 2t_1 + \frac{t_1}{2} = 3.5\ t_1$$

Q5.

Two sound sources (S_1 and S_2) are driven in phase by the same oscillator. Their sound is detected by a microphone arranged as shown in **Figure 3.** If the frequency of the oscillator is varied, what is the difference between the lowest frequency causing constructive interference and the lowest frequency causing destructive interference? Take the speed of sound in air to be 340 m/s.

Figure 3



A) 401 Hz
B) 136 Hz
C) 102 Hz
D) 453 Hz
E) 906 Hz

Ans:

$$\Delta L = 4.92 - 4.50 = 0.42 \text{ m}$$

$*$ Constructive Interference:

$$\Delta L = m\lambda = \frac{mv}{f} \Rightarrow f = \frac{mv}{\Delta L} \Rightarrow f_1 = \frac{v}{\Delta L}$$

$*$ Destructive Interference:

$$\Delta L = (2m+1)\frac{\lambda}{2} = \frac{(2m+1)v}{2f}$$

$$\Rightarrow f = \frac{(2m+1)v}{2\Delta L} \Rightarrow f_1 = \frac{v}{2\Delta L}$$

$*$ Difference:

$$\Delta f = \frac{v}{\Delta L} - \frac{v}{2\Delta L} = \frac{v}{2\Delta L} = \frac{340}{2 \times 0.42} = 401 \text{ Hz}$$

Q6.

A person is 30 m from a point sound source. At this distance, the sound level is 110 dB. If his ear is circular with a diameter of 8.4 mm, how much energy is transferred to his ear each second?

A) 5.5 μJ
B) 3.5 μJ
C) 8.1 μJ
D) 2.5 μJ
E) 7.2 μJ

Ans:

$$\beta = 10 \cdot \log\left(\frac{I}{I_o}\right) \rightarrow \frac{\beta}{10} = \log\frac{I}{I_o} \Rightarrow \frac{I}{I_o} = (10)^{\frac{\beta}{10}} \rightarrow I = I_0 \cdot (10)^{\frac{\beta}{10}}$$

$$\therefore I = 10^{-12} \times 10^{11} = 0.1\ W/m^2$$

$$I = \frac{P}{A} \rightarrow P = I \cdot A = I \cdot (\pi r^2) = \pi \times 0.1(4.2 \times 10^{-3})^2 = 5.5\ \mu W$$

$$\text{Energy} = \text{Power} \times \text{time} = 5.54 \times 1.0 = 5.54\ \mu J$$

Q7.

The fundamental frequency of a pipe open at both ends is 590 Hz. What will be the fundamental frequency if the pipe is closed at one end?

A) 295 Hz
B) 590 Hz
C) 118 Hz
D) 148 Hz
E) 522 Hz

Ans:

o → open, c → closed

$$\left.\begin{array}{l} f_o = \frac{v}{2L} \\ f_c = \frac{v}{4L} \end{array}\right\} \frac{f_c}{f_o} = \frac{v}{4L}, \frac{2L}{v} = \frac{1}{2} \Rightarrow f_c = \frac{f_o}{2} = \frac{590}{2} = 295\ \text{Hz}$$

Q8.

A car and a train are moving toward each other along a straight line, each moving with half the speed of sound. The train's whistle emits sound at frequency f_o. What frequency is heard by the passenger of the car?

A) $3f_o$
B) f_o
C) $2f_o$
D) $4f_o$
E) $f_o/2$

Ans:

$$f' = f_o \cdot \frac{v + v/2}{v - v/2} = f_o \cdot \left[\frac{\frac{3v}{2}}{\frac{v}{2}}\right] = 3f_o$$

Q9.

A steel tape is used for length measurement, and its markings are calibrated at 20.000 °C. When the temperature is 35.000 °C, a person uses the tape to measure a distance and found it to be 35.794 m. What is the actual distance? [$\alpha_{steel} = 1.200 \times 10^{-5}$ K^{-1}]

A) 35.800 m
B) 35.786 m
C) 35.794 m
D) 35.807 m
E) 35.133 m

Ans:

$$L_f = L_i(1 + \alpha\Delta T) \Rightarrow L_i = \frac{L_f}{1 + \alpha\Delta T} = \frac{35.794}{1 + (1.2 \times 10^{-5} \times 15)} = 35.7876 \text{ m}$$

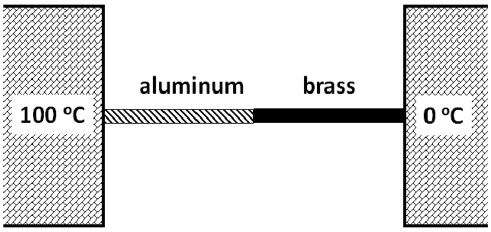
$$\text{Reduction Factor: } f = \frac{L_i}{L_f} = 0.99982$$

$$\therefore \text{Correct length measurement} = \frac{\text{Legth measurement}}{f} = \frac{35.794}{0.99982} = 35.800 \text{ m}$$

Q10.

An aluminum rod and a brass rod, of the same length (0.500 m) and cross sectional area (1.00 cm^2), are welded end-to-end and placed between two reservoirs, as shown in **Figure 4**. At steady state, find the rate of heat conduction through these two bars. Thermal conductivities are: k_{brass} = 109 W/m.K, k_{Al} = 205 W/m.K.

Figure 4



A) 1.42 W
B) 6.53 W
C) 3.15 W
D) 2 .94 W
E) 5.42 W

Ans:

Let T be the junction temperature

$$k_A \cdot \frac{(100-T)A}{L} = \frac{k_A \cdot T \cdot A}{L}$$

$$\Rightarrow 100\, k_A = (k_A + k_B)T$$

$$\therefore \mathrm{T} = \frac{100k_A}{k_A + k_B} = \frac{100 \times 205}{205 \times 109} = 65.3\ °\mathrm{C}$$

$$\therefore \mathrm{P_{cond}} = \frac{\mathrm{k_B\, T \cdot A}}{\mathrm{L}} = \frac{109 \times 65.3}{0.5} \times 10^{-4} = 1.42\ \mathrm{W}$$

Q11.

A 6.00-kg piece of copper is placed with 2.00 kg of ice that is initially at – 20.0 ^{o}C. The ice is in an insulated container of negligible mass and no heat is exchanged with the surroundings. After thermal equilibrium is reached, there is 1.20 kg of ice and 0.800 kg of liquid water. What was the initial temperature of copper?
The specific heats are: copper = 386 J/kg.K, ice = 2220 J/kg.K.

A) 153 ^{o}C
B) 38.4 ^{o}C
C) 115 ^{o}C
D) 100 ^{o}C
E) 102 ^{o}C

Ans:

Since there is ice/watermixture $\Rightarrow \mathrm{T_f} = 0\ °\mathrm{C}$

$$\left.\begin{aligned} \mathrm{Q_1} &= \mathrm{m_i \cdot c_i \cdot \Delta T_i} = 2 \times 2220 \times 20 = 88.8\ \mathrm{kJ} \\ \mathrm{Q_2} &= \mathrm{m_i \cdot L_f} = 0.8 \times 333 = 266.4\ \mathrm{kJ} \end{aligned}\right\} \text{heat gained by ice: } \mathrm{Q_i} = 355.2\ \mathrm{kJ}$$

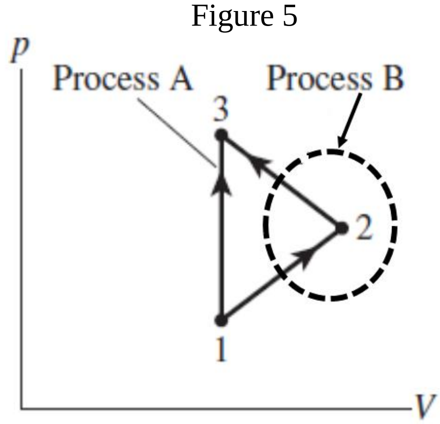
$$\Rightarrow \text{heat lost by copper: } \mathrm{Q_c} = -355.2\ \mathrm{kJ} = \mathrm{m_c \cdot C_c \cdot \Delta T_c}$$

$$\Rightarrow \Delta \mathrm{T_c} = -\frac{355.2 \times 10^3}{6 \times 386} = -153\ °\mathrm{C}$$

Q12.

Two processes take an ideal gas from state 1 to state 3 (having the same volume), as shown in **Figure 5**. Compare the work done by process A(direct path) to the work done by process B (path via state 2).

Figure 5



A) $W_A > W_B$
B) $W_A < W_B$
C) $W_A = W_B = 0$
D) $W_A = W_B > 0$
E) $W_A = W_B < 0$

Ans:

$$\left.\begin{matrix} W_{12} \rightarrow + \\ W_{23} \rightarrow - \end{matrix}\right\} \text{since } |W_{32}| > |W_{12}| \Rightarrow W_B < 0$$

$$W_{13} = 0 \text{ (no change in volume)}$$

$$\Rightarrow W_A > 0$$

$$\Rightarrow W_A > W_B$$

Q13.

An ideal gas is compressed to one-half its original volume. Rank the following processes in order from highest to lowest value of the final pressure: (1) a monatomic gas compressed isothermally; (2) a monatomic gas compressed adiabatically; (3) a diatomic gas compressed isothermally; (4) a diatomic gas compressed adiabatically.

A) 2, 4, (1 and 3) tie
B) 4, 2, (1 and 3) tie
C) (1 and 3) tie, 4, 2
D) (1 and 3) tie, 2, 4
E) 2, 1, 3, 4

Ans:

isothermal: $p_f = 2p_i \longrightarrow$ independent of gas

adiabatic: $p_f = \left(\frac{V_i}{V_f}\right)^{\gamma} p_i = 2^{\gamma} \cdot p_i = \begin{cases} 3.17\ p_i \rightarrow \text{monatomic} & (2) \\ 2.64\ p_i \rightarrow \text{diatomic} & (4) \end{cases}$

$\Rightarrow$ 2, 4, (1 and 3) tie

Q14.

A container with volume 1.48 L is initially evacuated. Then, it is filled with 0.226 g of an ideal gas. If the root-mean-square speed of the gas molecules is 182 m/s, what is the pressure of the gas?

A) 1.69 kPa
B) 6.02 kPa
C) 2.23 kPa
D) 3.05 kPa
E) 5.41 kPa

Ans:

$$v_{rms}^2 = \frac{3RT}{M} \rightarrow T = \frac{Mv_{rms}^2}{3R}$$

Let m = mass of the sample; M = molar mass

$$\Rightarrow n = \frac{m}{M}$$

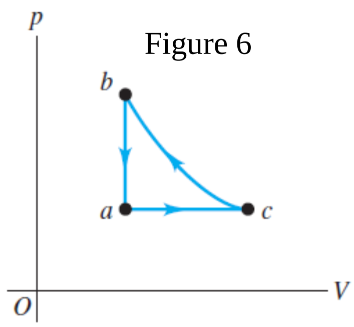
$$p = \frac{nRT}{V} = \frac{R}{V} \cdot \frac{m}{M} \cdot \frac{Mv_{rms}^2}{3R} = \frac{Mv_{rms}^2}{3V} = \frac{2.26 \times 10^{-4} \times (182)^2}{3 \times 1.48 \times 10^{-3}} = 1686\ P_a$$

Q15.

Three moles of an ideal gas are taken around the cycle *acb* shown in **Figure 6**. For this gas, C_p = 29.1 J/mol.K. Process *ac* is at constant pressure, process *ba* is at constant volume, and process *cb* is adiabatic. The temperatures are T_a = 300 K, T_b = 600 K, and T_c = 492 K. Calculate the total work for the cycle.

A) – 1.95 kJ
B) – 6.74 kJ
C) + 4.78 kJ
D) –3.17 kJ
E) zero

Figure 6



Ans:

$$C_V = C_P - R = 29.1 - 8.31 = 20.79\ J/mol \cdot K$$

$$W_{ba} = 0$$

$$W_{ac} = p \cdot \Delta V = nR\Delta T = 3 \times 8.31 \times (492 - 300) = 4786.56\ J$$

$$W_{cb} = -\Delta E_{int} = -nC_v\Delta T = -3 \times 20.79 \times (600 - 492) = -6735.96\ J$$

$$\Rightarrow W_{total} = 0 + 4786.56 - 6738.96 = -1949.4\ J$$

Q16.

Figure 1 shows a *pV*-diagram for the cyclic process traversed by an ideal gas, where process *bc* is isothermal. Find the total heat exchanged in the cycle.

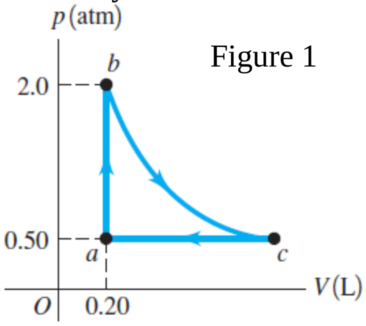


Figure 1

A) 25.7 J gained by the gas
B) 25.7 J lost by the gas
C) 56.2 J gained by the gas
D) 56.2 J lost by the gas
E) 30.4 J lost by the gas

Ans:

$$W_{ab} = 0$$

$$W_{bc} = nRT \cdot ln\left(\frac{V_f}{V_i}\right) = p_b \cdot V_b \cdot ln\left(\frac{p_b}{p_c}\right)$$

$$= 2 \times 1.01 \times 10^5 \times 2 \times 10^{-4} \times ln(4) = +56.006 \text{ J}$$

$$W_{ca} = p \cdot \Delta V = p_a \cdot (V_a - V_c) = p_a(V_a - 4V_a) = -3p_aV_a$$

$$= -3 \times 0.5 \times 1.01 \times 10^5 \times 2 \times 10^{-4} = -30.3 \text{ J}$$

$$W_{net} = 0 + 56.0 - 30.3 = -25.7 \text{ J}$$

For a cycle: $\Delta E_{int} = 0$

$$\Rightarrow Q_{net} = W_{net} = 25.7 \text{ J}$$

Q17.

Two moles of an ideal diatomic gas are cooled at constant pressure from 25.0 ^{o}C to –18.0 ^{o}C. What is the change in the entropy of the gas?

A) – 9.06 J/K
B) + 9.06 J/K
C) – 46.1 J/K
D) – 11.5 J/K
E) + 11.5 J/K

Ans:

$$\Delta S = n \cdot C_p \cdot ln\left(\frac{T_f}{T_i}\right) = 2 \times \frac{7}{2} \times 8.31 \times ln\left(\frac{-18 + 273}{25 + 273}\right) = -9.06 \text{ J / K}$$

Q18.

A 0.250 kg of water, initially at 85.0 ^{o}C, is allowed to cool slowly to room temperature (20.0 ^{o}C). The temperature of the air in the room (20.0 ^{o}C) does not change. What is the total entropy change of the system (water + air)?

A) +22.5 J/K
B) –22.5 J/K
C) –209 J/K
D) +232 J/K
E) +209 J/K

Ans:

W → Water; a → air

$$\Delta S_W = m_w \cdot c_w \cdot ln\left(\frac{T_f}{T_i}\right) = 0.25 \times 4190 \times ln\left(\frac{20+273}{85+273}\right) = -209.78\ \frac{J}{K}$$

$$Q_W = |m_w \cdot c_w \cdot \Delta T| = 0.25 \times 4190 \times 65 = 68087.5\ J$$

$$\Delta S_a = \frac{Q_W}{T_a} = \frac{68087.5}{20+273} = +232.26\,J/K$$

$$\therefore \Delta S_{total} = \Delta S_W + \Delta S_a = +22.48\ J/K$$

Q19.

A Carnot heat engine has an efficiency of 60.0% and performs 240 kJ of work in each cycle. Suppose the engine expels heat at room temperature (20.0 ^{o}C). What is the temperature of the hot reservoir?

A) 733 K
B) 323 K
C) 306 K
D) 353 K
E) 50 K

Ans:

$$\varepsilon = \frac{W}{Q_H} \rightarrow Q_H = \frac{W}{\varepsilon} = \frac{240}{0.6} = 400\,kJ$$

$$Q_L = Q_H - W = 400 - 240 = 160\,kJ$$

$$\frac{T_H}{T_L} = \frac{Q_H}{Q_L} \Rightarrow T_H = \frac{Q_H}{Q_L} \cdot T_L = \frac{400}{160} \times 293.15 = 733\ K$$

Q20.

An ideal refrigerator has a coefficient of performance of 2.25, runs on an input electrical power of 95.0 W, and keeps its inside compartment at 5.00 °C. If you put 12.0 kg of water at 31.0 °C into this refrigerator, how long will it take for the water to be cooled down to
5.00 °C?

A) 102 minutes
B) 115 minutes
C) 126 minutes
D) 212 minutes
E) 139 minutes

Ans:

$$Q_L = m_w \cdot c_w \cdot \Delta T = 12 \times 4190 \times 26 = 1307280 \text{ J}$$

$$K = \frac{Q_L}{W} = \frac{Q_L}{P \cdot t}$$

$$\Rightarrow t = \frac{Q_L}{K \cdot p} = \frac{1307280}{2.25 \times 95} = 6116 \text{ s} = 102 \text{ minutes}$$