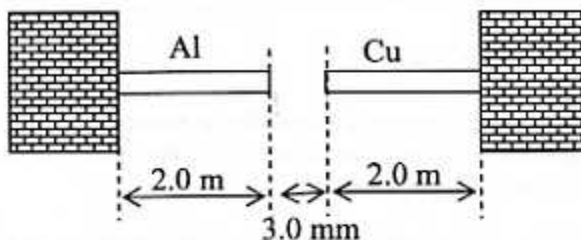


1. Two bars of aluminum and copper have initially the same length (2.0 m). They are fixed on one side to fixed walls and aligned as shown in the figure, leaving a 3.0 mm gap between them. How much should temperature be increased for the bars to touch?

- A. 12°C
 (B) 37°C
 C. 45°C
 D. 63°C
 E. 88°C



(Figure not to scale)

$$\Delta L = \Delta L_{Al} + \Delta L_{Cu}$$

$$\Delta L = L_0 \alpha_{Al} \Delta T + L_0 \alpha_{Cu} \Delta T$$

$$\Delta T = \frac{\Delta L}{L_0(\alpha_{Al} + \alpha_{Cu})} = \frac{3 \times 10^{-3} \text{ m}}{(2.0 \text{ m})(2.4 + 1.7) \times 10^{-5} \text{ } ^\circ\text{C}^{-1}} = 36.6^\circ\text{C}$$

2. Ten steel columns support a 1000-kg ceiling. The weight of the ceiling is uniformly distributed among all columns. The columns are cylinders of base radius 5.0 cm and height 3.0 m. What is the strain in each column?

- A. 6.2×10^{-12}
 B. 6.2×10^{-11}
 C. 6.2×10^{-8}
 (D) 6.2×10^{-7}
 E. 6.2×10^{-6}

Force on each column: $\frac{mg}{10}$

$$\text{Strain} = \frac{\Delta L}{L_0} = \frac{F/A}{Y_{\text{steel}}} = \frac{mg}{10(\pi r^2) Y_{\text{steel}}}$$

$$= \frac{(1000 \text{ kg})(9.8 \text{ m/s}^2)}{10\pi(0.05 \text{ m})^2(20 \times 10^{10} \text{ Pa})} = 6.2 \times 10^{-7}$$

3. A U-shaped tube initially contains a liquid A of density ρ . A column of liquid B density $\rho/3$ of height H is added to the left side. The new equilibrium is shown in the figure. Find h , the difference in height between the two sides.

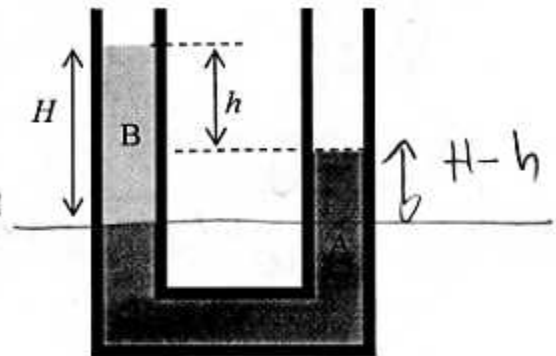
- A. $2H/3$
 B. $H/3$
 C. $H/2$
 D. $3H/2$
 E. $H/6$

Consider pressure at this level on both sides

$$\rho_B g H = \rho g (H - h)$$

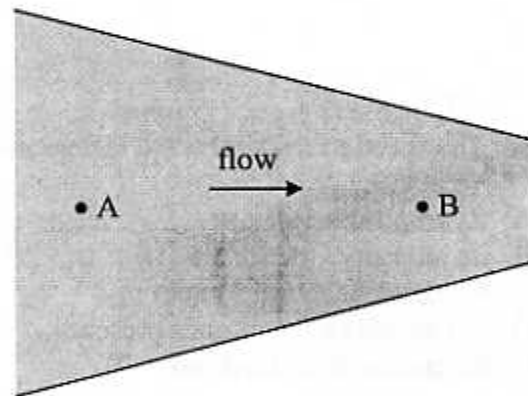
$$\frac{\rho}{3} H = \rho (H - h)$$

$$h = \frac{2}{3} H$$



4. Water flows through a horizontal pipe that narrows steadily as shown. Compare the speed of the water and the pressure at points A and B.

- A. $v_A < v_B$; $p_A < p_B$
 B. $v_A < v_B$; $p_A > p_B$
 C. $v_A > v_B$; $p_A < p_B$
 D. $v_A > v_B$; $p_A > p_B$
 E. $v_A > v_B$; $p_A = p_B$



Continuity: $A_A v_A = A_B v_B$ $A_A > A_B \Rightarrow v_B > v_A$

Bernoulli (for two points at equal height h)

$$\frac{1}{2} \rho v_A^2 + p_A = \frac{1}{2} \rho v_B^2 + p_B$$

$$p_A - p_B = \frac{1}{2} \rho (v_B^2 - v_A^2) \Rightarrow \text{If } v_B > v_A, p_A > p_B$$

5. A block of dimensions $4.0 \text{ cm} \times 4.0 \text{ cm} \times 3.0 \text{ cm}$ floats in a bucket of water as shown, with a third of the block above the surface. What is the mass of the block?

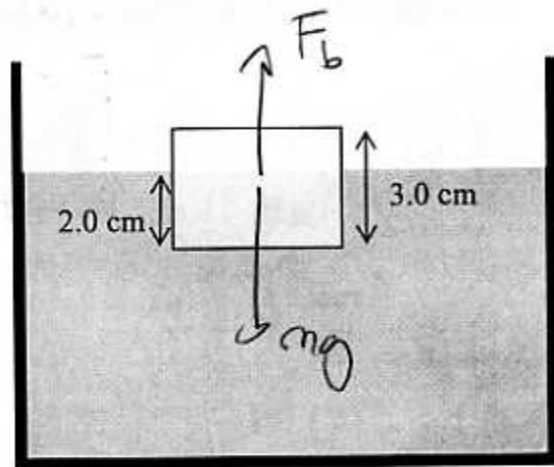
- A. 8.0 g
- B. 16 g
- C. 24 g
- D. 32 g
- E. 48 g

$$F_b - mg = 0$$

with $F_b = \rho_{\text{water}} V_{\text{submerged}} g$

$$m = \rho_w V_{\text{submerged}}$$

$$= \left(1000 \frac{\text{kg}}{\text{m}^3} \right) (0.04 \text{ m})^2 (0.02 \text{ m}) = 32 \times 10^{-3} \text{ kg}$$
$$= 32 \text{ g}$$

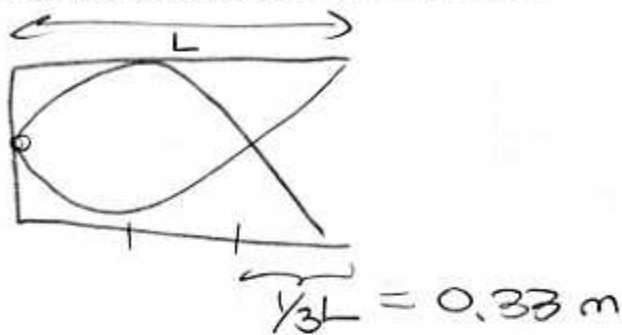


6. The speed of a sound wave is determined by:

- A. its amplitude
- B. its intensity
- C. the distance to the source
- D. the number of overtones present
- E. the transmitting medium

7. A 1.0 m long pipe has one open end and one closed end. Consider the second harmonic of this pipe. At which distance from the open end can we find a displacement node?

- A. 0.25 m
B. 0.33 m
C. 0.50 m
D. 0.67 m
E. 0.75 m



8. A source emits uniformly in all directions with a total power of 5.0 W. What is the power received by a microphone with an area of 2 mm^2 located 10 m away from the source?

- A. 5.0 nW
B. 8.0 nW
C. 12 nW
D. 26 nW
E. 48 nW

$$I_{\text{at } 10\text{m}} = \frac{5.0 \text{ W}}{4\pi(10\text{m})^2} = 3.98 \times 10^{-3} \text{ W/m}^2$$

$$P_{\text{microphone}} = I A_{\text{mic}} = \left(3.98 \times 10^{-3} \frac{\text{W}}{\text{m}^2}\right) (2 \times 10^{-6} \text{ m}^2) \\ = 8.0 \times 10^{-9} \text{ W}$$

9. An engine produces a 10 dB noise. If 20 of these engines work side by side, what is the sound intensity level produced by all of them?

- A. 20 dB
- B. 23 dB
- C. 30 dB
- D. 56 dB
- E. 100 dB

$$\beta_1 = 10 \log \frac{I_1}{I_0} \quad (1 \text{ engine})$$

$$\beta_n = 10 \log \frac{I_n}{I_0} \quad (n \text{ engines})$$

where $I_n = nI_1$

$$\beta_n = 10 \log \frac{nI_1}{I_0} = 10 \log n + 10 \log \frac{I_1}{I_0} = 10 \log n + \beta_1$$

$$\beta_{20} = 10 \log 20 + 10 = 23 \text{ dB}$$

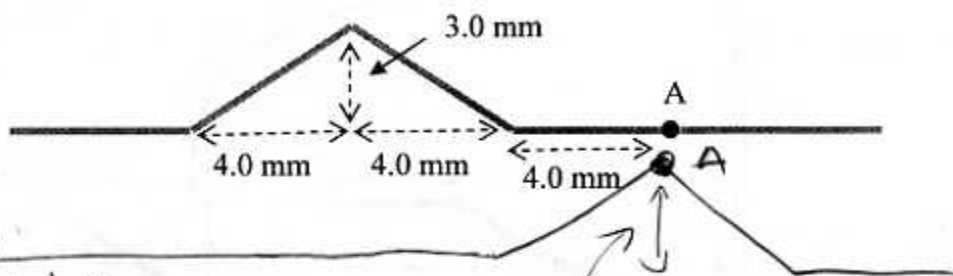
10. A balloon is filled with cold air and placed in a warm room. It is NOT in thermal equilibrium with the air in the room until:

- A. it rises to the ceiling
- B. it sinks to the floor
- C. it stops expanding
- D. it starts to contract
- E. none of the above

The air in the balloon will warm up, and thus the volume will expand, until it reaches thermal equilibrium with the room (ie, they are both at the same temperature)

11. A triangular pulse travels in a rope with a wave speed of 4.0 cm/s to the right. At $t = 0$, the wave is as shown in the figure. What is the total displacement of point A in the rope between $t = 0$ and $t = 0.2 \text{ s}$?

- A. 0
 B. 3.0 mm
 C. 4.0 mm
 D. 5.0 mm
 E. 8.0 mm



At $t = 0.2 \text{ s}$,
 profile is $(4 \frac{\text{cm}}{\text{s}})(0.2 \text{ s})$
 $= 8 \text{ mm}$ to the right

Point A moved 3.0 mm up

12. A speaker emits sound at a frequency f . In which of the following situations will a detector measure the highest frequency?

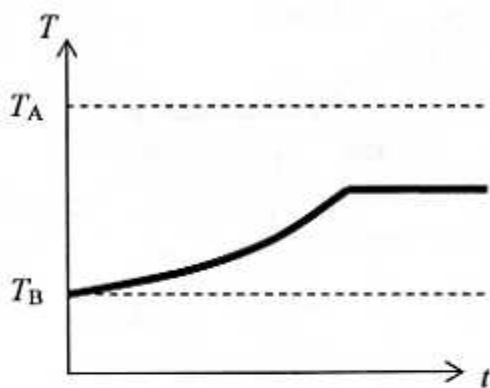
- A. The detector moving away from the speaker at $\frac{1}{2}$ the speed of sound.
 B. The detector moving toward the speaker at $\frac{1}{2}$ the speed of sound.
 C. The speaker moving away from the detector at $\frac{1}{2}$ the speed of sound.
 D. The speaker moving toward the detector at $\frac{1}{2}$ the speed of sound.
 E. Cases B and D have equal frequencies that are higher than cases A and C.

Options A and C produce a higher λ and lower f , so not worth a calculation.

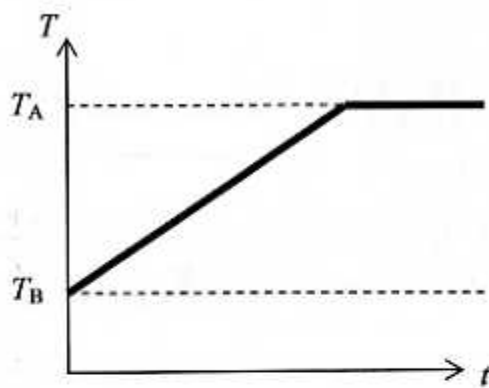
$$f_B = f_s \frac{v + \frac{v}{2}}{v} = \frac{3}{2} f_s$$

$$f_D = f_s \frac{v}{v - \frac{v}{2}} = 2 f_s$$

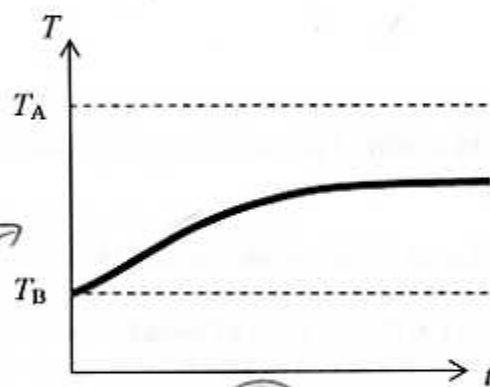
13. Two systems A and B have initial temperatures $T_A > T_B$. At $t = 0$, a rod connects them thermally so that heat can flow between the systems. The system A+B+rod is insulated, so no heat flows outside the system. Which of the following diagrams best describes the temperature of system B as a function of time?



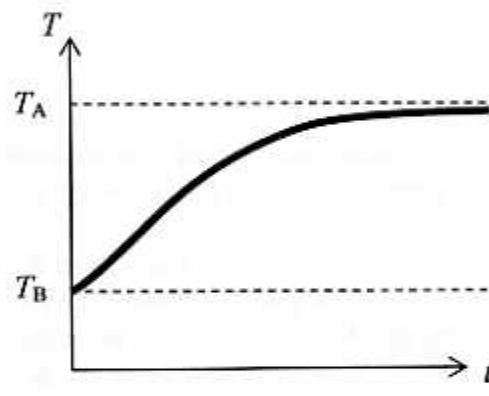
A



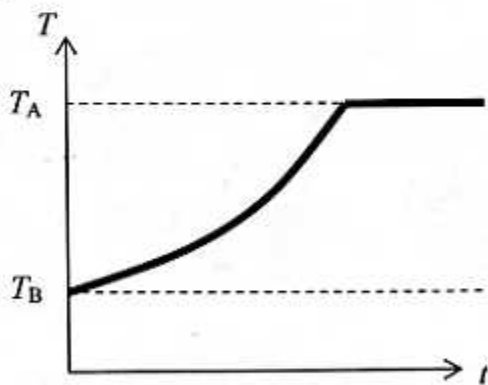
B



C



D

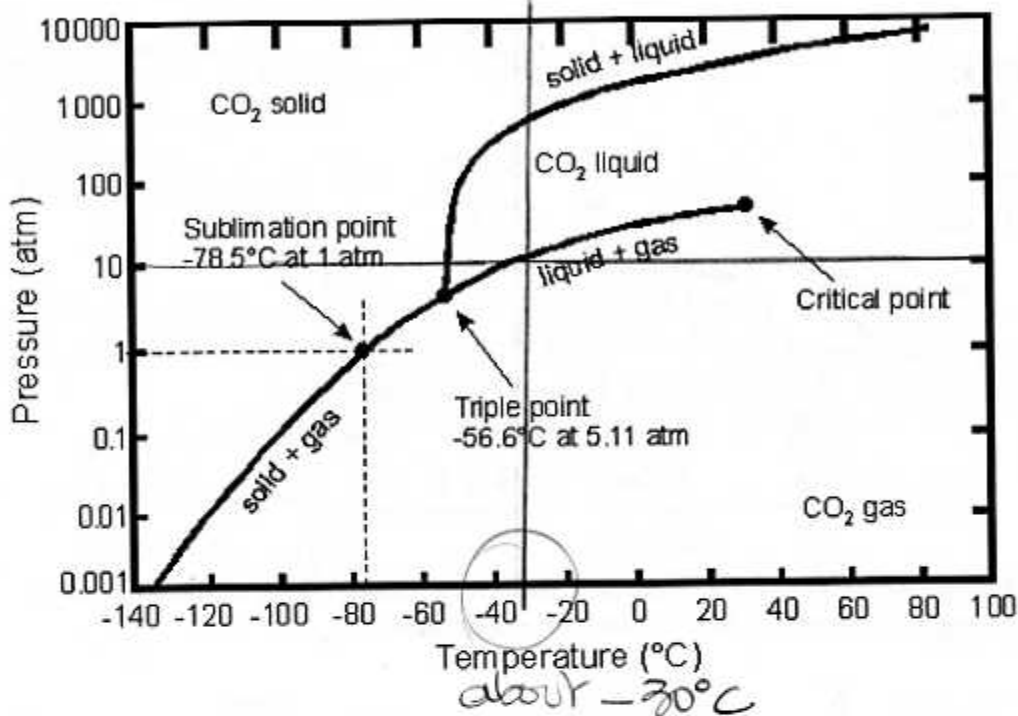


E

rate of heat transfer (slope) should decrease the temperatures in A and B get closer to one another

B, D, E: very wrong because it assumes that the temperature in system A remains constant (in spite of the heat transfer)

14. Consider the pT diagram of CO_2 shown below. At what temperature does CO_2 boil when the pressure is 10 atm?



Pressure-Temperature phase diagram for CO_2 .

- A. 0°C
 B. -30°C
 C. -50°C
 D. -56.6°C
 E. -78.5°C

15. A 1.0 m side cubic box contains oxygen at 2.5 atm and 27°C . How many molecules of oxygen are there in the box?

- A. 6.7×10^{21}
 B. 7.2×10^{22}
 C. 6.0×10^{23}
 D. 5.5×10^{24}
 E. 6.1×10^{25}

$$pV = nRT = \frac{N}{N_A} RT$$

$$N = N_A \frac{pV}{RT}$$

$$N = (6.022 \times 10^{23}) \frac{(2.5 \times 1.01 \times 10^5 \text{ Pa})(1.0 \text{ m})^3}{(8.31 \frac{\text{J}}{\text{mol K}})(273 + 27) \text{ K}}$$

$$= 6.1 \times 10^{25}$$

16. A high wind gusts along the outer surface of a $2\text{m} \times 3\text{m}$ window. If the window is rated to withstand a force equivalent to the weight of a 300 kg mass, what is the maximum wind velocity this window is rated for?

A. 103 km/hr
 B. 174 km/hr
 C. 252 km/hr
 D. 494 km/hr
 E. 817 km/hr

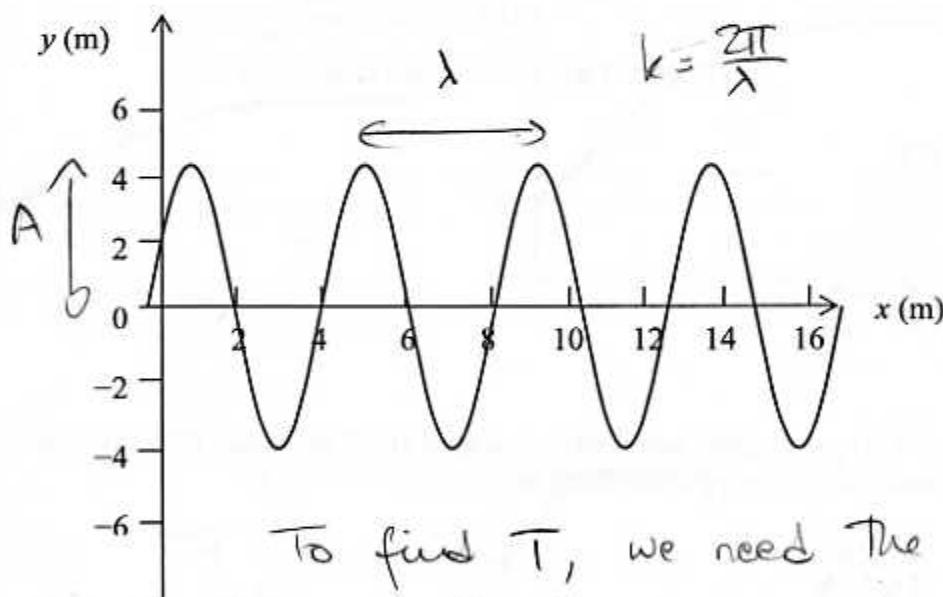
$$F = \frac{1}{2} \rho v^2 A \quad \rho_{\text{air}} = 1.20 \frac{\text{kg}}{\text{m}^3}$$

$$\frac{1}{2} \rho v^2 = \frac{mg}{A}$$

$$v = \sqrt{\frac{2mg}{\rho A}} = \sqrt{\frac{2(300\text{ kg})(9.8\text{ m/s}^2)}{(1.20 \frac{\text{kg}}{\text{m}^3})(6\text{ m}^2)}} = 28.6\text{ m/s}$$

$$28.6 \frac{\text{m}}{\text{s}} \cdot \frac{1\text{ km}}{1000\text{ m}} \cdot \frac{3600\text{ s}}{1\text{ h}} = 103\text{ km/h}$$

17. From a plot of $Y(x)$ for a transverse wave on a string, which of the following **cannot** be determined without further information?



To find T , we need the wave speed v

$$v = \frac{\lambda}{T}$$

- A. Wavelength λ
 B. Wave number k
 C. Amplitude A
 D. Period T
 E. All the above can be determined from this plot.

18. What is the absolute pressure 2.5 m below the surface of a pool filled with mercury, Hg? (Assuming one existed at ISU)

- A. 1.3 atm.
- B. 2.3 atm.
- C. 3.3 atm.
- D. 4.3 atm.
- E. None of the above

$$\begin{aligned} P &= P_{\text{atm}} + \rho_{\text{Hg}} gh \\ &= 1 \text{ atm} + \left(13600 \frac{\text{kg}}{\text{m}^3} \right) \left(9.8 \frac{\text{m}}{\text{s}^2} \right) (2.5 \text{ m}) \cdot \frac{1 \text{ atm}}{1.01 \times 10^5 \text{ Pa}} \\ &= 4.3 \text{ atm} \end{aligned}$$

19. Two identical containers, both at room temperature, are filled with He gas. Container A is at a pressure of 1 atmosphere and container B is at a pressure of 2 atmospheres. Which of the following statements about v_{rms} in container A, $v_{\text{rms}}(A)$, and v_{rms} in container B, $v_{\text{rms}}(B)$ is true?

- A. $v_{\text{rms}}(A) = 2 v_{\text{rms}}(B)$
- B. $v_{\text{rms}}(A) = \sqrt{2} v_{\text{rms}}(B)$
- C. $v_{\text{rms}}(A) = v_{\text{rms}}(B)$
- D. $v_{\text{rms}}(A) = (1/\sqrt{2}) v_{\text{rms}}(B)$
- E. $v_{\text{rms}}(A) = (1/2) v_{\text{rms}}(B)$

$$\frac{1}{2} m v_{\text{rms}}^2 = \frac{3}{2} kT$$

pressure is irrelevant
only T matters

20. A wall with thickness L made out of a material with thermal conductivity k separates a region on the left that is 40°C from a region on the right that is 20°C . Which of the following changes results in the greatest reduction of heat current through the wall?

- A. Double L
- B. Change the wall material to one with a thermal conductivity $k' = \frac{1}{2}k$.
- C. Decrease the temperature on the left to 30°C .
- D. Increase the temperature on the right to 30°C .
- E. All of the changes suggested result in the same reduction of heat current.

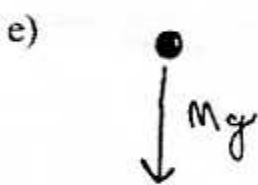
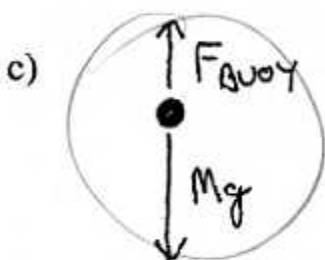
$$H = \frac{dQ}{dt} = kA \frac{T_L - T_R}{L}$$

21. How much heat is required to transform a 10-gram ice cube, originally at -30°C , into water at 70°C ?

- A. 2.93 kJ
- B. 33.4 kJ
- C. 35.6 kJ
- D. 6.90 kJ
- E. 75.3 kJ

$$\begin{aligned}
 Q &= Q_{\text{warm up ice to } 0^\circ\text{C}} + Q_{\text{melting}} + Q_{\text{warm up water to } 70^\circ\text{C}} \\
 &= mC_{\text{ice}}(0 + 30) + mL_{\text{melt}} + mC_{\text{water}}(70 - 0) \\
 &= (0.01 \text{ kg}) \left[\left(2100 \frac{\text{J}}{\text{kg}^\circ\text{C}} \right) (30^\circ\text{C}) + 334 \times 10^3 \frac{\text{J}}{\text{kg}} + \right. \\
 &\quad \left. + \left(4186 \frac{\text{J}}{\text{kg}^\circ\text{C}} \right) (70^\circ\text{C}) \right] = 6.90 \times 10^3 \text{ J}
 \end{aligned}$$

22. A solid aluminum ball is below the surface of a lake and is sinking through the water. Which of the following is an accurate free body diagram of the forces acting on this ball?



Mg always points down
 F_{Buoy} " " up
 (in this case, $|Mg| > |F_{Buoy}|$)

23. Two loudspeakers are located 5.0 m apart. A listener is 18 m from one and 19 m from the other. The two speakers emit in phase with the same amplitude and frequency. The transmitted frequency is swept through the audible range (20 Hz to 20 kHz). What is the lowest frequency at which the listener will hear a minimum signal because of destructive interference?

- (A) 172 Hz
 B. 343 Hz
 C. 516 Hz
 D. 686 Hz
 E. 860 Hz

Difference in path is $\frac{\lambda}{2}, 3\frac{\lambda}{2}, 5\frac{\lambda}{2}, \dots$
 $(2n-1)\frac{\lambda}{2}$

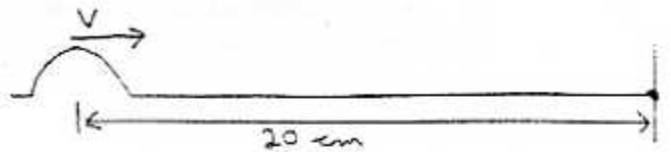
$$\Delta d = (2n-1)\frac{\lambda_n}{2}$$

$$\lambda_n = \frac{2\Delta d}{2n-1} \rightarrow f_n = \frac{v}{\lambda_n} = \frac{v}{2\Delta d} (2n-1)$$

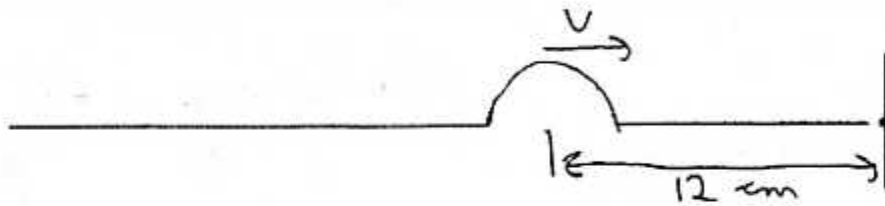
$$f_n = \frac{343 \text{ m/s}}{2(19-18)\text{m}} (2n-1) = 171.5 (2n-1)$$

$f_1 = 171.5 \text{ Hz}$
 (within range, so ok)

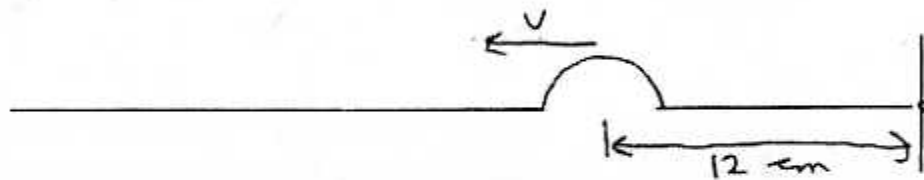
24. A pulse is moving down a string and at time $t = 0.00$ s has its center located 20 cm to the left of the wall to which the string is firmly clamped (shown at right). If the pulse has a velocity of 4.00 cm/s to the right, which figure best represents the string at $t = 8.00$ s?



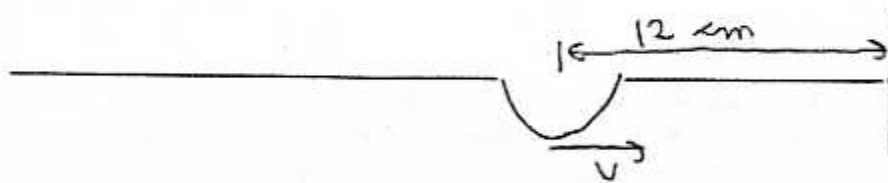
a)



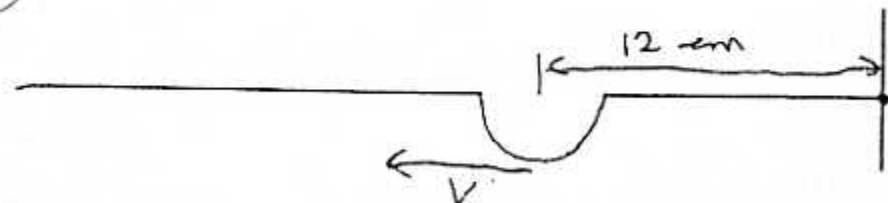
b)



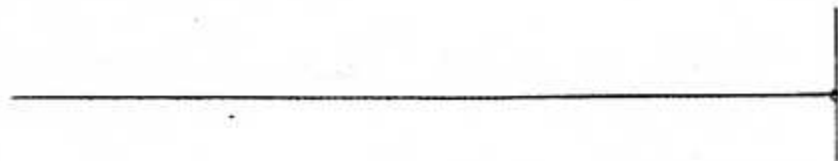
c)



d)



e)



Fixed end
 \Downarrow
 reversed
 waves moving
 in opposite
 direction

25. A bimetallic strip is made out of copper and aluminum and is shown at $T = 300 \text{ K}$. If the base of the strip is clamped in place and the strip is cooled to 100 K , what will happen?

ALUMINUM	COPPER
----------	--------

- A. The strip will lengthen, but stay straight.
B. The strip will lengthen, but also bend so as to have its tip point toward the right.
C. The strip will shorten, but stay straight.
 D. The strip will shorten, but also bend so as to have its tip point toward the left.
E. The strip will shorten, but also bend so as to have its tip point toward the right.

$\alpha_{Al} > \alpha_{Cu}$, so Al shrinks more than Cu,
and thus strip bends left.

26. A large rock is dropped into a pond. Some distance away a boat bobs up and down with a period of 6.0 s . The waves on the pond have a speed of 0.50 m/s . What is the distance between the crests (local maxima) of the wave?

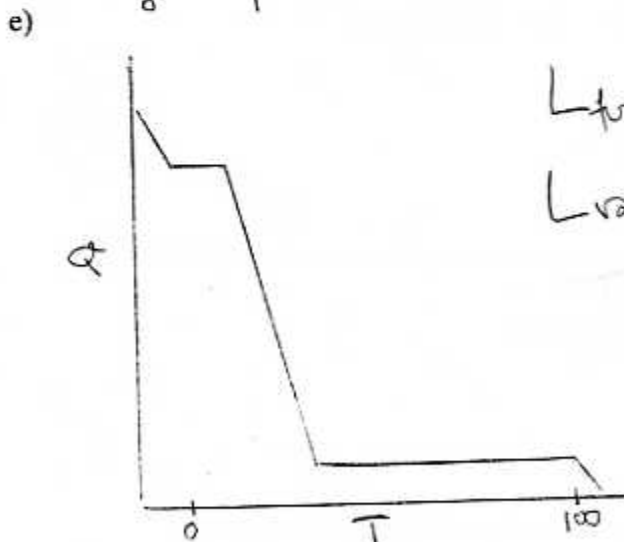
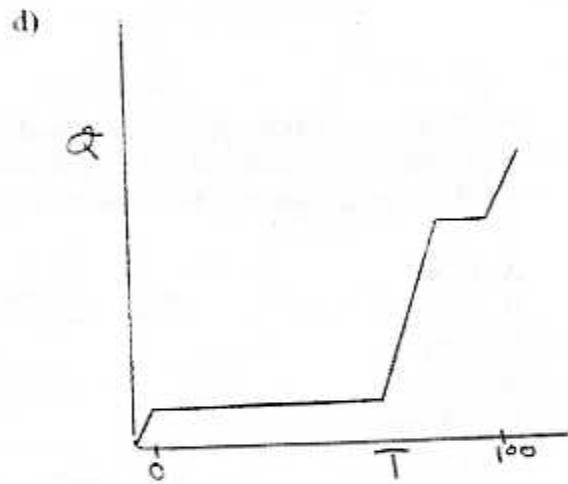
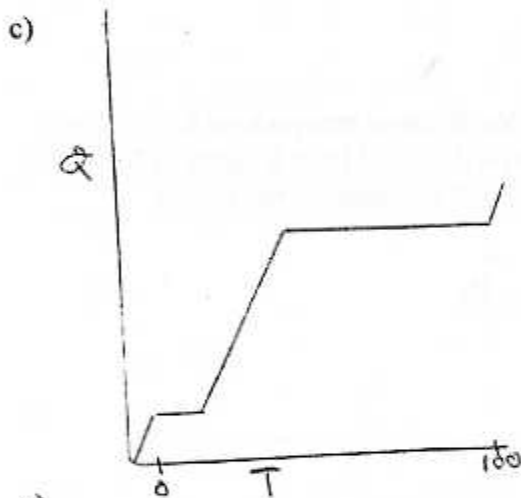
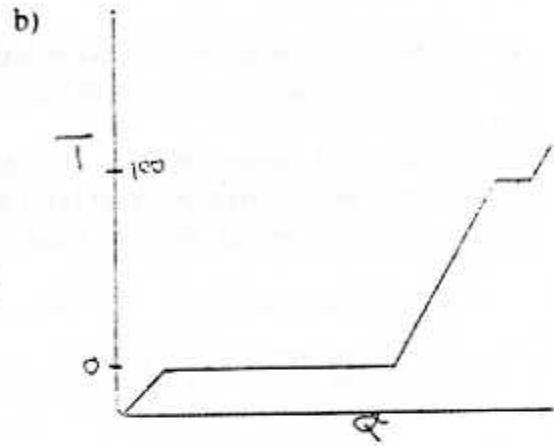
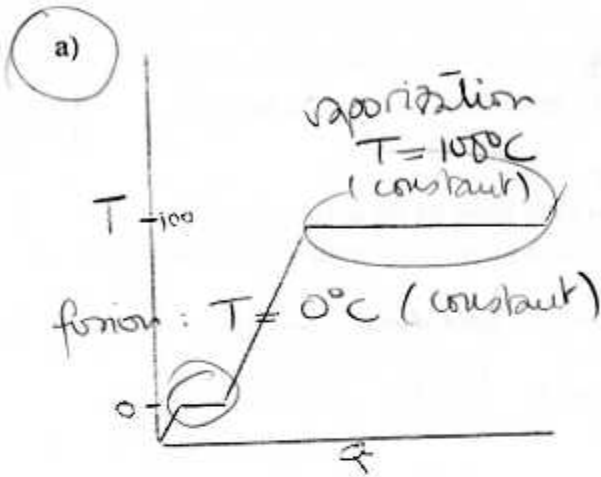
- A. 12 m
B. 6.0 m
 C. 3.0 m
D. 0.50 m
E. 0.33 m

$$v = 0.50 \text{ m/s}$$

$$T = 6.0 \text{ s}$$

$$\lambda = vT = 3.0 \text{ m}$$

27. Which of these plots best represents relation between temperature and heat input of an ice cube with an initial temperature below 0 °C warming up and finally transforming into steam with a temperature above 100 °C?



$$L_{\text{fusion}} = 334 \times 10^3 \text{ J/kg}$$

$$L_{\text{vap}} = 2256 \times 10^3 \text{ J/kg}$$