Please, sit in row C.

1 pt  Are you sitting in the seat assigned?

1. A ○ Yes, I am.
The paths of two small satellites, M1 = 2.00 kg and M2 = 9.00 kg, are shown below, drawn to scale, with M1 corresponding to the circular orbit. They orbit around a massive star, also shown below. The orbits are in the plane of the paper.

The period of M1 is \( T_1 = 26.0 \) years. Calculate the period of M2, in years.

2. \( A \quad 1.03 \times 10^2 \quad B \quad 1.16 \times 10^2 \quad C \quad 1.31 \times 10^2 \quad D \quad 1.48 \times 10^2 \quad E \quad 1.68 \times 10^2 \quad F \quad 1.89 \times 10^2 \quad G \quad 2.14 \times 10^2 \quad H \quad 2.42 \times 10^2 \)

**Kepler’s third law:**

\[
\frac{T_1^2}{T_2^2} = \frac{a_1^3}{a_2^3} \quad \Rightarrow \quad T_2 = T_1 \cdot \frac{a_2^3}{a_1^3}
\]

\[
T_2 = T_1 \cdot \left(\frac{a_2}{a_1}\right)^{3/2} = 26 \text{ yrs} \cdot \left(\frac{5}{2}\right)^{3/2}
\]

\[
T_2 = 102.8 \text{ yrs} \approx 103 \text{ yrs}
\]
Planet-X has a mass of $3.55 \times 10^{24}$ kg and a radius of 8450 km. What is the First Cosmic Speed i.e. the speed of a satellite on a low lying circular orbit around this planet? (Planet-X doesn’t have any atmosphere.)

\( \text{(in km/s)} \)

3.  
A $2.25$  
B $2.54$  
C $2.87$  
D $3.25$  
E $3.67$  
F $4.15$  
G $4.68$  
H $5.29$

What is the Second Cosmic Speed i.e. the minimum speed required for a satellite in order to break free permanently from the planet?

\( \text{(in km/s)} \)

4.  
A $5.63$  
B $7.49$  
C $9.96$  
D $1.32 \times 10^4$  
E $1.76 \times 10^3$  
F $2.34 \times 10^3$  
G $3.12 \times 10^3$  
H $4.14 \times 10^3$

First Cosmic Speed: 
\[ v_I = \sqrt{\frac{GM}{R_x}} \]

Second Cosmic Speed: 
\[ v_{II} = \sqrt{2} \cdot v_I \]

\[ v_I = \sqrt{\frac{6.67 \times 10^{-11} \cdot 3.55 \times 10^{24}}{8.45 \times 10^6}} = 5294 \text{ m/s} \]

\[ v_I \approx 5.29 \text{ km/s} \]

\[ v_{II} = \sqrt{2} \cdot v_I = 7.49 \text{ km/s} \]
The height of the Mercury column in the Toricelli barometer is $h = 760$ mm here on Earth at sea level. See figure.

3 pt What would be the height of the Mercury column on the surface of the Moon? The Moon has no atmosphere, and the gravitational field is six times weaker on the Moon than here on Earth.

5. A $127$ mm, six times shorter.
   B $760$ mm, same as on Earth.
   C $0$ mm.
   D $4560$ mm, six times higher.

No atmosphere $\Rightarrow p = 0$

3 pt What would be the height of the Mercury column inside a Moon-base where an Earth-like air atmosphere is maintained for comfortable living? (The Toricelli barometer has sufficient amount of Mercury, and the glass tube can be extended, if necessary.)

6. A $127$ mm, six times shorter.
   B $4560$ mm, six times higher.
   C $0$ mm.
   D $760$ mm, same as on Earth.

$\rho = \sigma g h$

Mercury is a liquid. The density of a liquid is constant. The gravitational acceleration is six times less on the Moon, therefore we need a Mercury column six times taller to hold the same pressure.
4 pt An object weighs 75.8 N in air. When it is suspended from a force scale and completely immersed in water the scale reads 20.3 N. Determine the density of the object.

\[(\text{in kg/m}^3)\]

\[
\begin{align*}
\text{A} & : 4.55 \times 10^2 \\
\text{B} & : 5.32 \times 10^2 \\
\text{C} & : 6.23 \times 10^2 \\
\text{D} & : 7.29 \times 10^2 \\
\text{E} & : 8.53 \times 10^2 \\
\text{F} & : 9.98 \times 10^2 \\
\text{G} & : 1.17 \times 10^3 \\
\text{H} & : 1.37 \times 10^3
\end{align*}
\]

\[
\begin{align*}
\text{In air:} & \quad F_1 = mg \\
\text{In water:} & \quad F_2 + B = mg \\
\text{Archimedes:} & \quad B = m_{\text{fluid}} \cdot g = S_{\text{fluid}} \cdot V_{\text{obj}} \cdot g = S_{\text{fluid}} \cdot \frac{m_{\text{obj}} \cdot q}{S_{\text{obj}}} = \frac{S_{\text{fluid}}}{S_{\text{obj}}} \cdot m_{\text{obj}} \cdot q = \frac{S_{\text{fluid}}}{S_{\text{obj}}} \cdot F_1 \\
\Rightarrow S_{\text{obj}} = S_{\text{fluid}} \cdot \frac{F_1}{F_1 - F_2} & = S_{\text{fluid}} \cdot \frac{F_1}{B} \\
S_{\text{obj}} & = 1000 \cdot \frac{75.8}{75.8 - 20.3} = 1366 \text{ kg/m}^3
\end{align*}
\]
The figure illustrates flow through a pipe with diameters of 1 mm and 2 mm and with different elevations. \( p_x \) is the pressure in the pipe, and \( v_x \) is the speed of a non-viscous incompressible fluid at locations \( x = Q,R,S,T, \) or \( U. \)

Select the correct answers.

\( \triangleright \) \( p_T \) is ... \( p_R. \)
8. \( \text{A} \) Greater than \( \text{B} \) Less than \( \text{C} \) Equal to

\( \triangleright \) \( p_R \) is ... \( p_S. \)
9. \( \text{A} \) Greater than \( \text{B} \) Less than \( \text{C} \) Equal to

\( \triangleright \) \( v_S \) is ... \( 2v_U. \)
10. \( \text{A} \) Greater than \( \text{B} \) Less than \( \text{C} \) Equal to

\( \triangleright \) 9: \( p_T < p_S \): when you climb in a fluid, the pressure decreases. (When you dive, the pressure increases.)

\( \triangleright \) 8: \( p_S < p_R \): when the fluid slows down, its pressure increases. (When the fluid speeds up, its pressure decreases.)

\( \triangleright \) 10: \( v_S > 2v_U \): since \( A_u = 4A_s \) (due to \( A = \pi r^2 = \frac{\pi d^2}{4} \) ) therefore \( v_S = 4v_U \) due to continuity: \( A \cdot v = \text{constant}. \)
A rock band uses a wall built out of 31 identical speakers. If one single speaker can produce a sound level of 95.5 dB in the front row area, then what is the sound level produced by the whole wall? (in dB)

Intensity from one speaker: $I_1$

Intensity from 31 speakers: $I_{31} = 31 \cdot I_1$

Sound level from one speaker:

$$S_1 = 10 \cdot \log \left( \frac{I_1}{I_0} \right) = 95.5 \text{ dB}$$

Sound level from 31 speakers:

$$S_{31} = 10 \cdot \log \left( \frac{I_{31}}{I_0} \right) =$$

$$= 10 \cdot \log \left( 31 \cdot I_1 / I_0 \right) =$$

$$= 10 \cdot \log (31) + 10 \cdot \log \left( \frac{I_1}{I_0} \right) =$$

$$= 14.9 \text{ dB} + 95.5 \text{ dB} = 110.4 \text{ dB}$$
A truck horn emits a sound with a frequency of 238 Hz. The truck is moving on a straight road with a constant speed. If a person standing on the side of the road hears the horn at a frequency of 256 Hz, then what is the speed of the truck? Use 340 m/s for the speed of the sound.

\[ f_o = f_s \cdot \frac{c + v_o}{c - v_s} \]

\[ f_o = f_s \cdot \frac{c}{c - v_s} \]

\[ c f_o - v_s f_o = c f_s \]

\[ c f_o - c f_s = v_s f_o \]

\[ c \cdot \frac{f_o - f_s}{f_o} = v_s \]

\[ v_s = 340 \cdot \frac{256 - 238}{256} = 23.9 \text{ m/s} \]
An organ pipe is 1.70 m long and it is open at one end and closed at the other end. What are the frequencies of the lowest three harmonics produced by this pipe? The speed of sound is 340 m/s. Only one answer is correct.

13. A $200 \text{Hz}, 400 \text{Hz}, 600 \text{Hz}$
   B $100 \text{Hz}, 300 \text{Hz}, 500 \text{Hz}$
   C $200 \text{Hz}, 300 \text{Hz}, 400 \text{Hz}$
   D $50 \text{Hz}, 100 \text{Hz}, 150 \text{Hz}$
   E $50 \text{Hz}, 150 \text{Hz}, 250 \text{Hz}$
   F $100 \text{Hz}, 200 \text{Hz}, 300 \text{Hz}$
   G $200 \text{Hz}, 600 \text{Hz}, 1000 \text{Hz}$
   H $50 \text{Hz}, 100 \text{Hz}, 200 \text{Hz}$

An open-closed pipe holds waves with frequencies $f_1, 3f_1, 5f_1, 7f_1, \ldots$ waves with $f_1, 3f_1, 5f_1, 7f_1$ frequencies.

**Fundamental mode:**

$$L = \frac{1}{4} \lambda_1 \Rightarrow 4L = \lambda_1$$

**Speed-wavelength-frequency relation:**

$$C = \lambda f \Rightarrow f_1 = \frac{C}{\lambda_1} = \frac{C}{4L}$$

$$f_1 = \frac{340}{4 \cdot 1.7} = 50 \text{Hz}$$ fundamental frequency

Therefore the frequencies are:

$$50 \text{Hz}, 150 \text{Hz}, 250 \text{Hz}, 350 \text{Hz}, 450 \text{Hz} \ldots$$

$$f_1, 3f_1, 5f_1, 7f_1, 9f_1$$
3 pt A bimetallic strip is held fixed at the bottom end as shown in the figure.

The metal on the left has a coefficient of linear heat expansion of $\alpha_{\text{left}} = 3.57 \times 10^{-5}$ 1/K, the metal on the right has $\alpha_{\text{right}} = 1.99 \times 10^{-5}$ 1/K. When the strip is cooled, it will... (complete the sentence)

14. A... bend right.
    B... bend left.
    C... remain straight.

The metal on the left has a larger coefficient of linear heat expansion, therefore it will contract more. When the strip is cooled, it will bend to the left.
9.10 liters of Nitrogen gas at 47.0°C temperature and 1.80 atm pressure contains how many moles?

\[ pV = nRT \quad \Rightarrow \quad n = \frac{pV}{RT} \]

\[ R = 8.31 \text{ J/(molK)} \]

\[ p = 1.80 \text{ atm} = 1.823 \cdot 10^5 \text{ Pa} \]

\[ V = 9.10 \text{ l} = 9.1 \cdot 10^{-3} \text{ m}^3 \]

\[ T = 47.0 \text{ °C} = 320 \text{ K} \]

\[ n = \frac{1.823 \cdot 10^5 \cdot 9.1 \cdot 10^{-3}}{8.31 \cdot 320} = 0.624 \text{ mol} \]
A 21.6 liter gas bottle contains $7.90 \times 10^{23}$ Helium molecules at a temperature of 358 K. What is the thermal energy of the gas? (in J)

- A $5.86 \times 10^3$
- B $7.32 \times 10^3$
- C $9.15 \times 10^3$
- D $1.14 \times 10^4$
- E $1.43 \times 10^4$
- F $1.79 \times 10^4$
- G $2.23 \times 10^4$
- H $2.79 \times 10^4$

Thermal energy of a gas:

$$E_{\text{th}} = \frac{f}{2} N k_B T$$

$k_B = 1.38 \times 10^{-23}$ J/K : Boltzmann constant

Helium : $f = 3$ : monoatomic gas

$N = 7.90 \times 10^{23}$

$T = 358$ K

$$E_{\text{th}} = \frac{3}{2} \times 7.9 \times 10^{23} \times 1.38 \times 10^{-23} \times 358$$

$$E_{\text{th}} \approx 5854 \text{ J}$$