Nagy,

Tibor

Keep this exam **CLOSED** until advised by the instructor.

50 minute long closed book exam.

Fill out the bubble sheet: last name, first initial, **student number (PID)**. Leave the section, code, form and signature areas empty.

Three two-sided handwritten 8.5 by 11 help sheets are allowed.

When done, hand in your **test** and your **bubble sheet**.

Thank you and good luck!

Posssibly useful constants:

- $g = 9.81$ m/s^2
- $G = 6.67\times10^{-11}$ Nm^2/kg^2
- $\rho_{water} = 1000$ kg/m^3 = 1 kg/l = 1 g/cm^3
- 1 atm = 101.3 kPa = 760 mmHg
- $N_A = 6.02\times10^{23}$ 1/mol
- $R = 8.31$ J/(molK)
- $k_B = 1.38\times10^{-23}$ J/K
- 0 °C = 273.15 K

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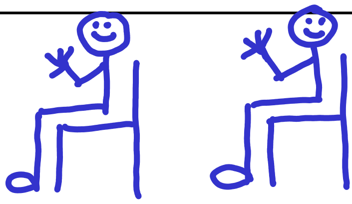
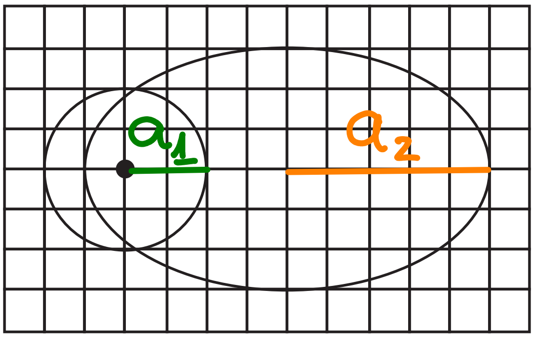
Please, sit in row C.



1 pt Are you sitting in the seat assigned?

1.A ◯ Yes, I am.

4 pt 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 T1 = 26.0 years. Calculate the period of M2, in years.

2. **A**◯ 1.03×10^2 **B**◯ 1.16×10^2 **C**◯ 1.31×10^2 **D**◯ 1.48×10^2
E◯ 1.68×10^2 **F**◯ 1.89×10^2 **G**◯ 2.14×10^2 **H**◯ 2.42×10^2

Kepler's third law:

$$\frac{T_1^2}{T_2^2} = \frac{a_1^3}{a_2^3} \Rightarrow T_2^2 = T_1^2 \cdot \frac{a_2^3}{a_1^3} \Rightarrow$$

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

$$T_2 = 102.8\text{yrs} \approx 103\text{yrs}$$

| *3 pt* | Planet-X has a mass of 3.55×10^{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.)

(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

| *3 pt* | What is the Second Cosmic Speed *i.e.* the minimum speed required for a satellite in order to break free permanently from the planet?

(in km/s*)*

4. **A**◯ 5.63 **B**◯ 7.49 **C**◯ 9.96 **D**◯ 1.32×10^1
E◯ 1.76×10^1 **F**◯ 2.34×10^1 **G**◯ 3.12×10^1 **H**◯ 4.14×10^1

First Cosmic Speed: $v_I = \sqrt{\frac{GM}{R_X}}$

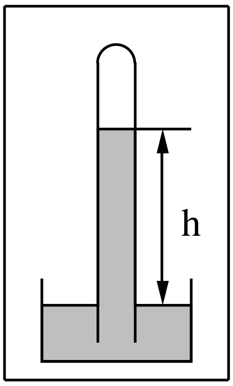
Second Cosmic Speed: $v_{II} = \sqrt{2} \cdot v_I$

$$v_I = \sqrt{\frac{6.67 \cdot 10^{-11} \cdot 3.55 \cdot 10^{24}}{8.45 \cdot 10^{6}}} = 5294 \, m/s$$

$$v_I \cong 5.29 \, km/s$$

$$v_{II} = \sqrt{2} \cdot v_I = 7.49 \, km/s$$

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 ⇒ $p = 0$

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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.

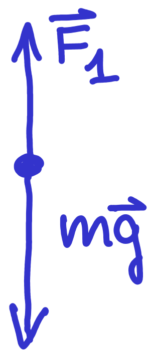
$p = \rho g h$

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.

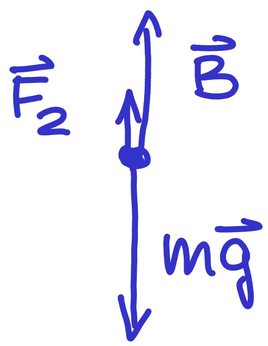
4 pt An object weighs 75.8 N in air. When it is suspended from a force scale and completely immersed in water the scale reads 20.3 N. Determine the density of the object.
(*in* `kg/m^3`)

7. **A**◯ 4.55×10^2 **B**◯ 5.32×10^2 **C**◯ 6.23×10^2 **D**◯ 7.29×10^2
E◯ 8.53×10^2 **F**◯ 9.98×10^2 **G**◯ 1.17×10^3 **H**◯ 1.37×10^3

In air:



In water:



Archimedes:

$$B = m_{fluid} \cdot g = \rho_{fluid} \cdot V_{obj} \cdot g$$

$$F_1 = mg \qquad F_2 + B = mg$$

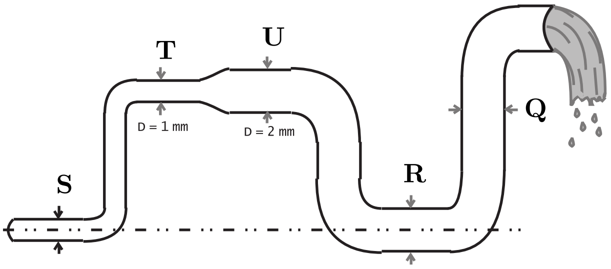
$$F_1 = F_2 + B$$

$$F_1 - F_2 = B = \rho_{fluid} \cdot V_{obj} \cdot g = \rho_{fluid} \cdot \frac{m_{obj}}{\rho_{obj}} \cdot g = \frac{\rho_{fluid}}{\rho_{obj}} \cdot m_{obj} \cdot g = \frac{\rho_{fluid}}{\rho_{obj}} \cdot F_1$$

$$\Rightarrow \rho_{obj} = \rho_{fluid} \cdot \frac{F_1}{F_1 - F_2} = \rho_{fluid} \cdot \frac{F_1}{B}$$

$$\rho_{obj} = 1000 \cdot \frac{75.8}{75.8 - 20.3} = 1366 \text{ kg/m}^3$$

6 pt 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.

▷ p_S is ... p_R.
8. **A**◯ Greater than **B**◯ Less than **C**◯ Equal to

▷ p_T is ... p_S.
9. **A**◯ Greater than **B**◯ Less than **C**◯ Equal to

▷ v_S is ... $2v_U$.
10. **A**◯ Greater than **B**◯ Less than **C**◯ Equal to

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

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

→ 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: $A \cdot v =$ constant.

4 pt 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*)*

11. **A**◯ 62.4 **B**◯ 83.0 **C**◯ 110.4 **D**◯ 146.9
E◯ 195.3 **F**◯ 259.8 **G**◯ 345.5 **H**◯ 459.5

Intensity from one speaker: I_1

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

Sound level from one speaker:

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

Sound level from 31 speakers:

$$S_{31} = 10 \cdot \log(I_{31} / I_0) =$$

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

$$= \underbrace{10 \cdot \log(31)}_{14.9 \text{ dB}} + \underbrace{10 \cdot \log(I_1 / I_0)}_{S_1 = 95.5 \text{ dB}} =$$

$$= 14.9 + 95.5 = 110.4 \text{ dB}$$

4 pt 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.
(in m/s*)*

12. **A**◯ 2.12×10^{1} **B**◯ 2.39×10^{1} **C**◯ 2.70×10^{1} **D**◯ 3.05×10^{1}
E◯ 3.45×10^{1} **F**◯ 3.90×10^{1} **G**◯ 4.40×10^{1} **H**◯ 4.98×10^{1}

observer: $v_o = 0\ m/s$

Source frequency: $f_s = 238\ Hz$
Observed frequency: $f_o = 256\ Hz$
The shift is up, therefore the truck is moving toward the observer.
Doppler formula:

$$f_o = f_s \cdot \frac{c \pm v_o}{c \pm v_s} \Rightarrow f_o = f_s \cdot \frac{c \pm 0}{c - v_s}$$

$$f_o = f_s \cdot \frac{c}{c - v_s}$$

$$cf_o - v_s f_o = cf_s$$

$$cf_o - cf_s = v_s f_o$$

$$c \cdot \frac{f_o - f_s}{f_o} = v_s$$

$$v_s = 340 \cdot \frac{256 - 238}{256} = 23.9\ m/s$$

4 pt 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 Hz, 400 Hz, 600 Hz
B◯ 100 Hz, 300 Hz, 500 Hz
C◯ 200 Hz, 300 Hz, 400 Hz
D◯ 50 Hz, 100 Hz, 150 Hz
E◯ 50 Hz, 150 Hz, 250 Hz
F◯ 100 Hz, 200 Hz, 300 Hz
G◯ 200 Hz, 600 Hz, 1000 Hz
H◯ 50 Hz, 100 Hz, 200 Hz

An open-closed pipe holds $\frac{1}{4}; \frac{3}{4}; \frac{5}{4}; \frac{7}{4}, \ldots$ 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:

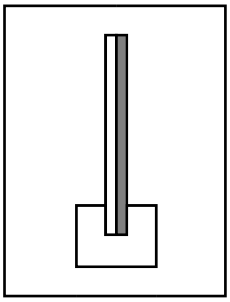
$$c = \lambda f \Rightarrow f_1 = \frac{c}{\lambda_1} = \frac{c}{4L}$$

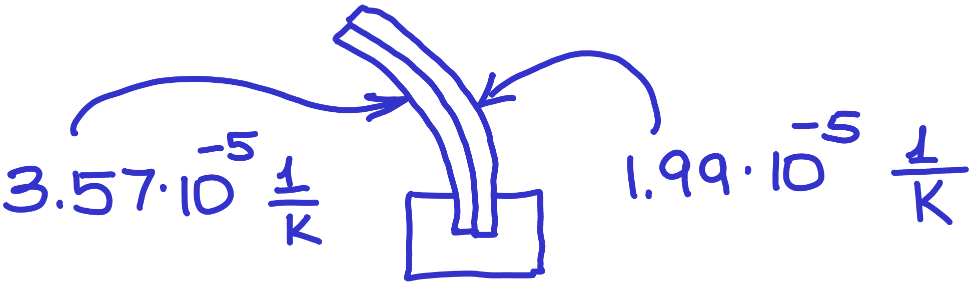
$$f_1 = \frac{340}{4 \cdot 1.7} = 50\,\text{Hz}$$ } fundamental frequency

Therefore the frequencies are:

$$\underbrace{50\,\text{Hz}}_{f_1}, \underbrace{150\,\text{Hz}}_{3\cdot f_1}, \underbrace{250\,\text{Hz}}_{5\cdot f_1}, \underbrace{350\,\text{Hz}}_{7\cdot f_1}, \underbrace{450\,\text{Hz}}_{9\cdot f_1} \ldots$$

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.

4 pt 9.10 liters of Nitrogen gas at 47.0°C temperature and 1.80 atm pressure contains how many moles?

15. **A** ◯ 0.488 **B** ◯ 0.552 **C** ◯ 0.624 **D** ◯ 0.705
E ◯ 0.796 **F** ◯ 0.900 **G** ◯ 1.017 **H** ◯ 1.149

Ideal Gas Law:

$$pV = nRT \Rightarrow n = \frac{pV}{RT}$$

$R = 8.31 \ J/(molK)$

$p = 1.80 \ atm = 1.823 \cdot 10^5 \ Pa$

$V = 9.10 \ l = 9.1 \cdot 10^{-3} \ m^3$

$T = 47.0°C = 320 \ K$

$$n = \frac{1.823 \cdot 10^5 \cdot 9.1 \cdot 10^{-3}}{8.31 \cdot 320} = 0.624 \ mol$$

4 pt A 21.6 liter gas bottle contains 7.90×10^{23} Helium molecules at a temperature of 358 K. What is the thermal energy of the gas?
(in J)

16. **A**◯ 5.86×10^{3} **B**◯ 7.32×10^{3} **C**◯ 9.15×10^{3} **D**◯ 1.14×10^{4}
E◯ 1.43×10^{4} **F**◯ 1.79×10^{4} **G**◯ 2.23×10^{4} **H**◯ 2.79×10^{4}

Thermal energy of a gas:

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

$k_B = 1.38 \cdot 10^{-23}$ J/K : Boltzmann const.

Helium : $f = 3$: monoatomic gas

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

$T = 358$ K

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

$E_{th} \cong 5854$ J