Nagy,

Tibor

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

120 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.

Four 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
- $G = 6.67 \times 10^{-11}$ 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
- $c_{water} = 4.1868$ kJ/(kg°C) = 1 kcal/(kg°C)
- 1 cal = 4.1868 J
- $\sigma = 5.67\times10^{-8}$ W/(m^{2}K^4)
- $b = 2.90\times10^{-3}$ m·K

Posssibly useful Moments of Inertia:

- Solid homogeneous cylinder: $I_{CM} = (1/2)MR^2$
- Solid homogeneous sphere: $I_{CM} = (2/5)MR^2$
- Thin spherical shell: $I_{CM} = (2/3)MR^2$
- Straight thin rod with axis through center: $I_{CM} = (1/12)ML^2$
- Straight thin rod with axis through end: $I = (1/3)ML^2$

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Please, sit in seat:

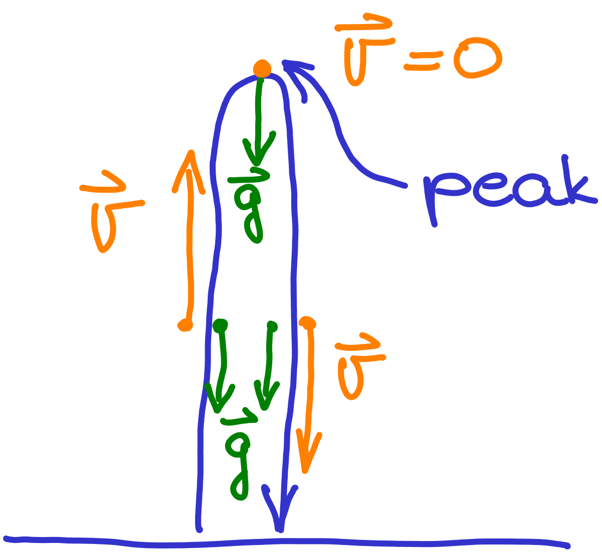
Thank you!

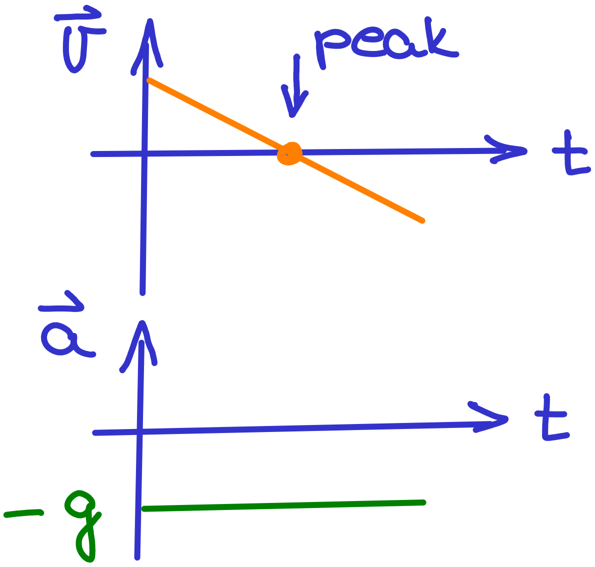
1 pt Are you sitting in the seat assigned?

1.A ◯ Yes, I am.

$\boxed{\textit{3 pt}}$ A tennis ball is tossed straight up into the air. It flies up, it reaches the peak position, and then it falls back down. What can we tell about the ball's velocity and acceleration, when the ball is at the peak of its trajectory? (Only one answer is correct.)

2.A◯ The velocity points up, and the acceleration is zero.
B◯ The velocity points down, and the acceleration points up.
C◯ The velocity points up, and the acceleration points down.
D◯ The velocity points down, and the acceleration is zero.
E◯ The velocity is zero, and the acceleration points down.
F◯ Both the velocity and the acceleration are zero.
G◯ Both the velocity and the acceleration point down.
H◯ Both the velocity and the acceleration point up.
I◯ The velocity is zero, and the acceleration points up.





$\boxed{4\ pt}$ A small, single engine airplane is about to take off. The airplane becomes airborne, when its speed reaches 177.0 km/h. The conditions at the airport are ideal, there is no wind. When the engine is running at its full power, the acceleration of the airplane is 4.50 m/s^2. What is the minimum required length of the runway?
(in m*)*

3. **A**◯ 3.65×10^1 **B**◯ 4.85×10^1 **C**◯ 6.45×10^1 **D**◯ 8.58×10^1
E◯ 1.14×10^2 **F**◯ 1.52×10^2 **G**◯ 2.02×10^2 **H**◯ 2.69×10^2

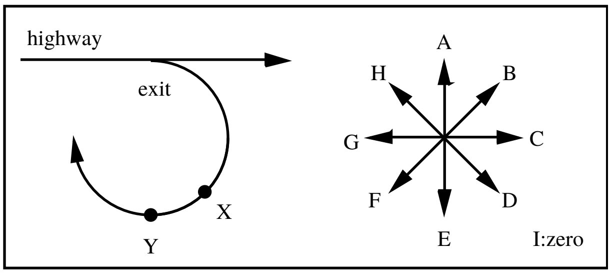
$$3.6\ km/h = 1\ m/s$$

$$177\ km/h = 49.17\ m/s$$

$$v^2 = 2ad \Rightarrow d = \frac{v^2}{2a}$$

$$d = \frac{49.17^2}{2 \cdot 4.5} = 269\ m$$

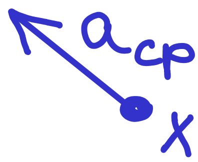
A car is exiting the highway on a circular exit ramp. (See figure.)



$\boxed{\textit{3 pt}}$ The driver slows the car down to the posted speed limit, enters the exit ramp and then maintains a constant speed. When the car is at point **X** on the ramp, which vector best represents the direction of the car's acceleration?

4.A◯ A.
B◯ B.
C◯ C.
D◯ D.
E◯ E.
F◯ F.
G◯ G.
H◯ H.
I◯ I: the acceleration is zero.

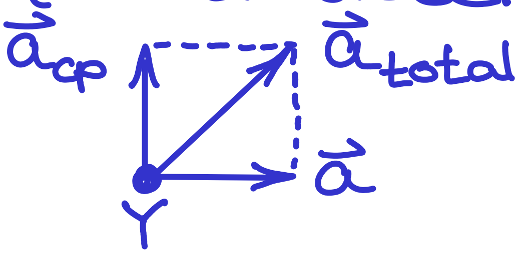
At location X centripetal acceleration only:



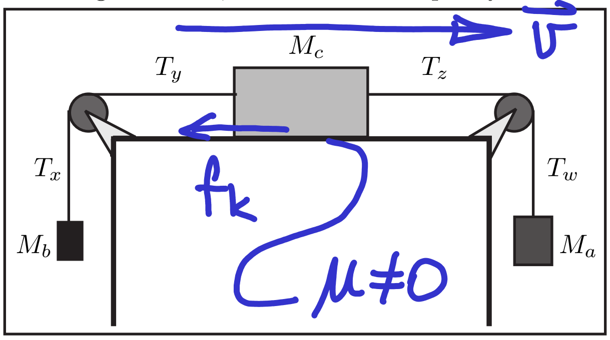
$\boxed{\textit{3 pt}}$ After passing point **X** but before reaching point **Y** the driver starts to push the brake pedal and applies the brakes for the rest of the exit ramp. Which vector best represents the direction of the car's acceleration when the car is at point **Y**?

5.A◯ A.
B◯ B.
C◯ C.
D◯ D.
E◯ E.
F◯ F.
G◯ G.
H◯ H.
I◯ I: the acceleration is zero.

At location Y centripetal acceleration and deceleration combined:



In the figure below, assume that the pulleys are massless and frictionless.



constant velocity
$\Rightarrow a = 0$

$\boxed{12\ pt}$ The masses of the blocks are M_a=3.50 kg, M_b=2.00 kg, M_c=6.00 kg, and there is friction between the horizontal plane and M_c, ($\mu_k \neq 0$). M_c is observed to travel at a constant velocity.

▷ T_x is .... T_y.
6. A◯ True B◯ False C◯ Greater than D◯ Less than E◯ Equal to

▷ T_x is .... M_b*g.
7. A◯ True B◯ False C◯ Greater than D◯ Less than E◯ Equal to

▷ M_c is moving to the right.
8. A◯ True B◯ False C◯ Greater than D◯ Less than E◯ Equal to

▷ The magnitude of the total force on M_c is .... 0.
9. A◯ True B◯ False C◯ Greater than D◯ Less than E◯ Equal to

▷ T_w is .... T_y.
10. A◯ True B◯ False C◯ Greater than D◯ Less than E◯ Equal to

▷ M_b accelerates upward.
11. A◯ True B◯ False C◯ Greater than D◯ Less than E◯ Equal to

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$\Rightarrow T_x = T_y$ b/c the pulley is frictionless.

$\Rightarrow T_x = M_b \cdot g$ b/c the acceleration is zero.

$\Rightarrow$ The system is moving to the right b/c $M_a > M_b$ ($M_a = 3.5$kg ; $M_b = 2.0$kg)

$\Rightarrow F_{net} = 0$ on M_c b/c $a = 0$

$\Rightarrow T_w > T_y$ because $T_y + f_k = T_z = T_w$

$\Rightarrow a = 0$ b/c the system is moving with constant velocity

$\boxed{3\ pt}$ There are 148 steps between the ground floor and the sixth floor in a building. Each step is 16.4 cm tall. It takes 4 minutes and 22 seconds for a person with a mass of 89.2 kg to walk all the way up. How much work did the person do?
(in J*)*

12. **A**◯ 1.33×10^4 **B**◯ 1.55×10^4 **C**◯ 1.82×10^4 **D**◯ 2.12×10^4
E◯ 2.48×10^4 **F**◯ 2.91×10^4 **G**◯ 3.40×10^4 **H**◯ 3.98×10^4

$\boxed{3\ pt}$ What was the average power performed by the person during the walk?
(in W*)*

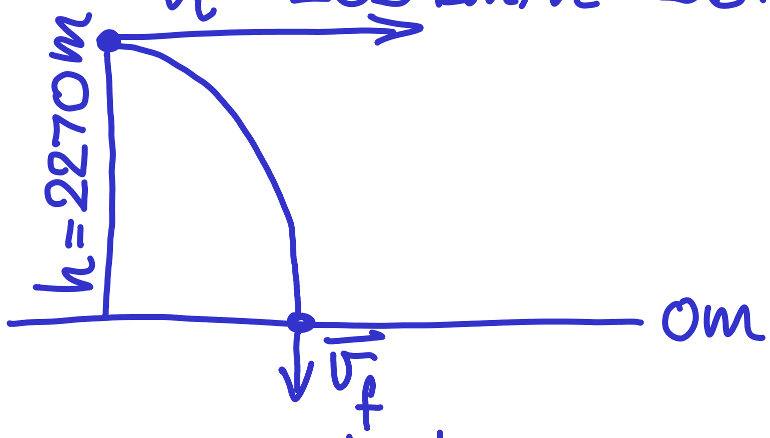
13. **A**◯ 3.70×10^1 **B**◯ 4.33×10^1 **C**◯ 5.06×10^1 **D**◯ 5.92×10^1
E◯ 6.93×10^1 **F**◯ 8.11×10^1 **G**◯ 9.48×10^1 **H**◯ 1.11×10^2

$$W = mgh = mg \cdot Nh_1 = 89.2 \cdot 9.81 \cdot$$
$$\cdot 148 \cdot 0.164 = 2.12 \cdot 10^4 \text{ J}$$
$$P = \frac{W}{t} = \frac{2.12 \cdot 10^4}{262} = 81.1 \text{ W}$$

$\boxed{5\ pt}$ An airplane is flying with a speed of 205 km/h at a height of 2270 m above the ground. A parachutist whose mass is 76.5 kg, jumps out of the airplane, opens the parachute and then lands on the ground with a speed of 3.15 m/s. How much energy was dissipated on the parachute by the air friction?
(in MJ*)*

14. **A**◯ 5.99×10^{-1} **B**◯ 8.69×10^{-1} **C**◯ 1.26 **D**◯ 1.83
E◯ 2.65 **F**◯ 3.84 **G**◯ 5.57 **H**◯ 8.08

$\vec{v}_i = 205\,km/h = 56.94\,m/s$



$3.6\,\frac{km}{h} = 1\,\frac{m}{s}$

Energy balance:

$$PE_i + KE_i = \underbrace{PE_f}_{=0} + KE_f + \Delta E_{th}$$

$$PE_i + KE_i - KE_f = \Delta E_{th}$$

$$\Delta E_{th} = mgh + \frac{1}{2}mv_i^2 - \frac{1}{2}mv_f^2 =$$

$$= 76.5 \cdot 9.81 \cdot 2270 + \frac{1}{2} \cdot 76.5 \cdot 56.94^2 -$$

$$-\frac{1}{2}76.5 \cdot 3.15^2 = 1.83\,MJ$$

$\boxed{4\ pt}$ A 610 kg automobile slides across an icy street at a speed of 59.7 km/h and collides with a parked car which has a mass of 855 kg. The two cars lock up and slide together. What is the speed of the two cars just after they collide? *(in* km/h*)*

15. **A**◯ 1.59×10^1 **B**◯ 1.99×10^1 **C**◯ 2.49×10^1 **D**◯ 3.11×10^1
E◯ 3.88×10^1 **F**◯ 4.86×10^1 **G**◯ 6.07×10^1 **H**◯ 7.59×10^1

Conservation of (linear) momentum always applies to any kind of collisions:

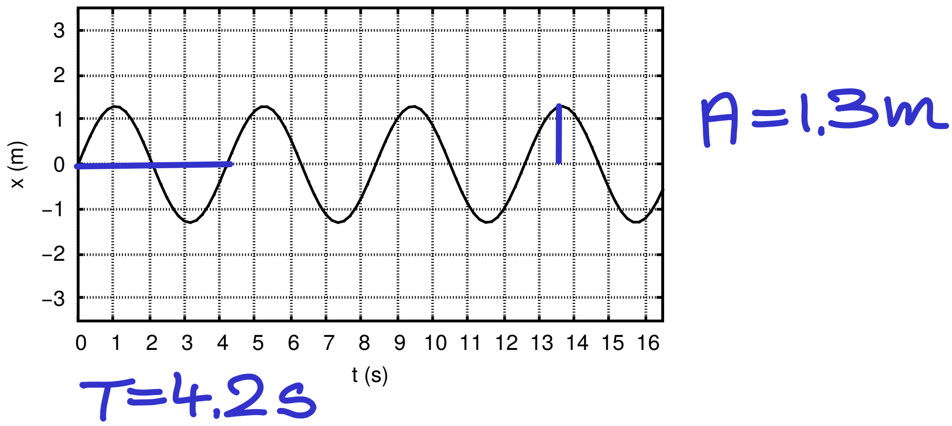
$$m_1 \cdot v_i + m_2 \cdot 0 = (m_1 + m_2) \cdot v_f$$

$$\frac{m_1}{m_1 + m_2} \cdot v_i = v_f$$

$$v_f = \frac{610}{610 + 855} \cdot 59.7 = 24.9\ \frac{\text{km}}{\text{h}}$$

Stay in km/h, don't convert to m/s!

The graph shows the x-displacement as a function of time for a particular object undergoing simple harmonic motion.



This function can be described by the following formula:
x(t) = Asin(ωt), where x and A are measured in meters, t is measured in seconds, ω is measured in rad/s.

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2 pt Using the graph determine the amplitude A of the oscillation.
(in m)

16. **A**◯ 7.00×10^{-1} **B**◯ 1.00 **C**◯ 1.30 **D**◯ 1.60
E◯ 2.20 **F**◯ 3.10 **G**◯ 3.40 **H**◯ 4.60

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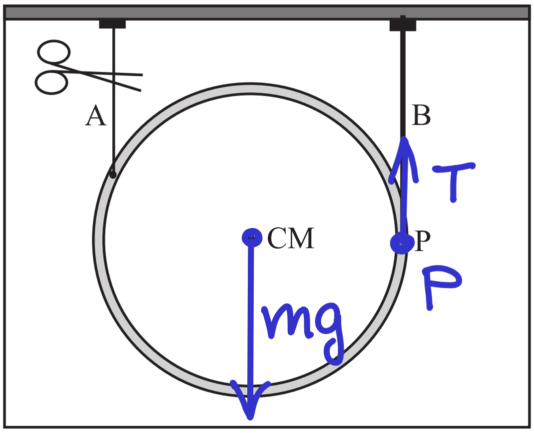
2 pt Determine the period T of the oscillation.
(in s)

17. **A**◯ 2.60 **B**◯ 3.80 **C**◯ 4.20 **D**◯ 5.00 **E**◯ 5.40 **F**◯ 6.60 **G**◯ 7.40 **H**◯ 8.20

$\boxed{4\ pt}$ A thin circular hoop with radius r and mass m is suspended vertically by two thin strings, A and B as shown in the figure. The center of the mass of the hoop is at the same height as the point P where string B is attached.



Hoop: $I_{CM} = mr^2$

Parallel axis theorem:

$I_P = I_{CM} + mr^2 = 2mr^2$

Which of the equations below represents the initial angular acceleration α of the hoop when the string A is cut? (Hint: Use the parallel axis theorem.)

18.A◯ mgr
B◯ $(2g)/r$
C◯ mg/r
D◯ $mg/(2r)$
E◯ $g/(2r)$
F◯ g/r
G◯ mgr^2

Rotational Newton's second law with respect to pivot P:

$$\tau = I_P \cdot \alpha$$

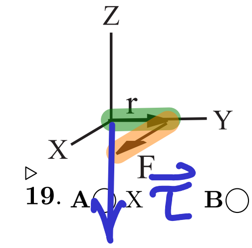
$$mgr = 2mr^2 \cdot \alpha$$

$$\frac{g}{2r} = \alpha$$

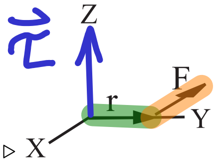
$\boxed{\textit{6 pt}}$ A body (not shown) has its center of mass (CM) at the origin. In each case below give the direction for the torque τ with respect to the CM on the body due to force **F** acting on the body at a location indicated by the vector **r**.

Torque: $\vec{\tau} = \vec{r} \times \vec{F}$

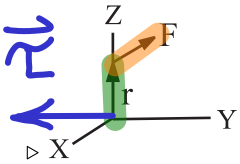
Right hand rule.



▷ **19.** **A**◯ X **B**◯ -X **C**◯ Y **D**◯ -Y **E**◯ Z **F**◯ -Z

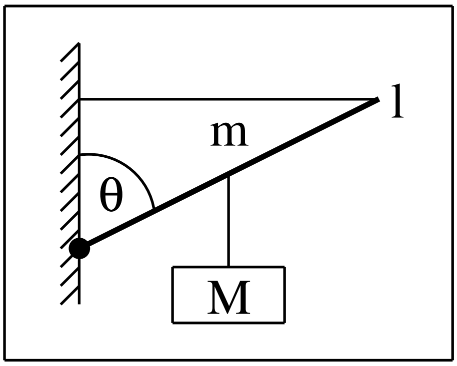


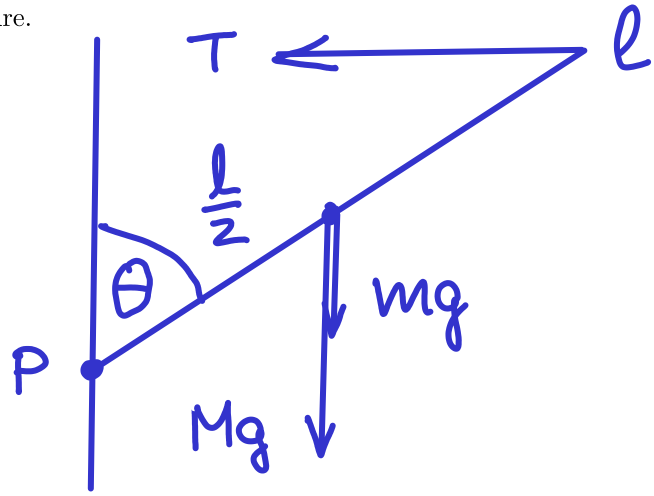
▷ **20.** **A**◯ X **B**◯ -X **C**◯ Y **D**◯ -Y **E**◯ Z **F**◯ -Z



▷ **21.** **A**◯ X **B**◯ -X **C**◯ Y **D**◯ -Y **E**◯ Z **F**◯ -Z

A crate with a mass of M = 73.5 kg is suspended by a rope from the midpoint of a uniform boom. The boom has a mass of m = 137 kg and a length of l = 9.12 m. The end of the boom is supported by another rope which is horizontal and is attached to the wall as shown in the figure.





2 pt The boom makes an angle of $\theta = 56.4°$ with the vertical wall. Calculate the tension in the vertical rope.
(in N*)*

22. **A** ◯ 4.42×10^2 **B** ◯ 5.00×10^2 **C** ◯ 5.65×10^2 **D** ◯ 6.38×10^2
E ◯ 7.21×10^2 **F** ◯ 8.15×10^2 **G** ◯ 9.21×10^2 **H** ◯ 1.04×10^3

$$Mg = 73.5 \cdot 9.81 = 721\,N$$

3 pt What is the tension in the horizontal rope?
(in N*)*

23. **A** ◯ 8.79×10^2 **B** ◯ 1.17×10^3 **C** ◯ 1.55×10^3 **D** ◯ 2.07×10^3
E ◯ 2.75×10^3 **F** ◯ 3.66×10^3 **G** ◯ 4.86×10^3 **H** ◯ 6.47×10^3

Torque balance wrt pivot P:

$$Mg \cdot \frac{l}{2} \cdot \sin\theta + mg \cdot \frac{l}{2} \cdot \sin\theta = T \cdot l \cdot \cos\theta$$

$$\frac{1}{2}(M+m)g\tan\theta = T$$

$$T = \frac{1}{2}(73.5 + 137) \cdot 9.81 \cdot \tan(56.4°)$$

$$T = 1554\,N$$

5 pt Planet-X has a mass of 8.31×10^{24} kg and a radius of 9300 km. What is the Escape Speed *i.e.* the minimum speed required for a satellite in order to break free permanently from the planet?
(in km/s*)*

24. **A** ◯ 3.58 **B** ◯ 4.47 **C** ◯ 5.59 **D** ◯ 6.99
E ◯ 8.73 **F** ◯ 1.09×10^{1} **G** ◯ 1.36×10^{1} **H** ◯ 1.71×10^{1}

Escape speed: $v_{II} = \sqrt{\frac{2GM}{R}}$

$G = 6.67 \cdot 10^{-11} \frac{Nm^2}{kg}$

$M = 8.31 \cdot 10^{24}$ kg

$R = 9300\text{ km} = 9.3 \cdot 10^{6}$ m

$$v_{II} = \sqrt{\frac{2 \cdot 6.67 \cdot 10^{-11} \cdot 8.31 \cdot 10^{24}}{9.3 \cdot 10^{6}}}$$

$$v_{II} = 10{,}918 \frac{m}{s} \cong 10.9 \frac{km}{s}$$

2 pt Which one weighs more, one kilogram iron or one kilogram feather?

25.A◯ It depends on the type of the iron and the feather.
B◯ The feather weighs more.
C◯ The iron weighs more.
D◯ They weigh the same.

They both weigh 9.81 N.

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2 pt Which one displaces more water, one kilogram wood or one kilogram styrofoam?

26.A◯ They displace the same amount of water.
B◯ The wood displaces more water.
C◯ It depends on the type of the wood and the styrofoam.
D◯ The styrofoam displaces more water.

Since they both float, they both displace 1 kg of water.

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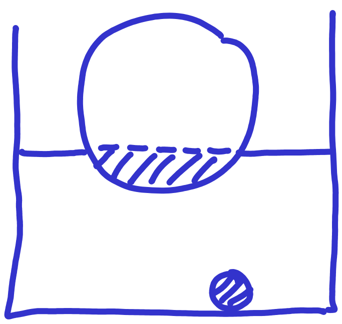
2 pt Which one displaces more water, one kilogram iron or one kilogram styrofoam?

27.A◯ The styrofoam displaces more water.
B◯ The iron displaces more water.
C◯ It depends on the type of the iron and the styrofoam.
D◯ They displace the same amount of water.

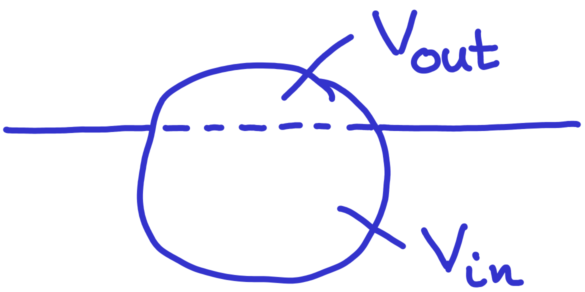


The styrofoam displaces 1 kg of water, because it floats on the surface.

The iron displaces water equivalent to its volume: $V = \frac{m}{\rho_{Fe}}$. Since the density of iron is greater than one $\left(\frac{kg}{\ell}\right)$, the displaced water is less than a kilogram.

$\boxed{4\ pt}$ A large tree trunk is floating in the sea. The density of the sea water is 1025 kg/m^3, the density of the trunk is 735 kg/m^3. What fraction of the trunk's volume is above the surface of the water?

28. **A**◯ 0.242 **B**◯ 0.283 **C**◯ 0.331 **D**◯ 0.387
E◯ 0.453 **F**◯ 0.530 **G**◯ 0.620 **H**◯ 0.726



water: $\rho_w = 1025\ \frac{kg}{m^3}$

trunk: $\rho_t = 735\ \frac{kg}{m^3}$

volume: $V = V_{in} + V_{out}$

Archimedes:

$$B = m_w \cdot g = \rho_w \cdot V_{in} \cdot g$$

Floating on the surface:

$$m_t \cdot g = B$$

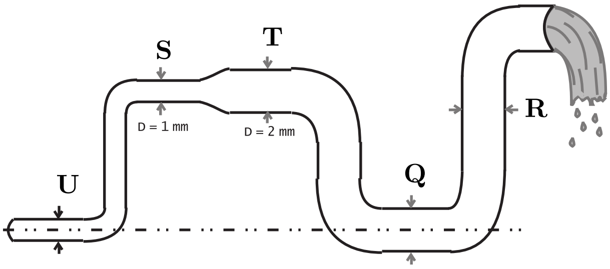
$$\rho_t \cdot V \cdot g = \rho_w \cdot V_{in} \cdot g$$

$$\left.\frac{\rho_t}{\rho_w} = \frac{V_{in}}{V}\right\}$$ fraction of volume in the water

Fraction of volume out: $1 - \frac{V_{in}}{V} =$

$$= 1 - \frac{\rho_t}{\rho_w} = 1 - \frac{735}{1025} = 0.283$$

$\boxed{6\ pt}$ 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_Q is … p_T.
29. **A**◯ Greater than **B**◯ Less than **C**◯ Equal to

▷ p_Q is … p_U.
30. **A**◯ Greater than **B**◯ Less than **C**◯ Equal to

▷ v_U is … $2v_T$.
31. **A**◯ Greater than **B**◯ Less than **C**◯ Equal to

→ $P_Q > P_T$ b/c pressure increases, when you dive deeper into a fluid (hydrostatic pressure)

→ $P_Q > P_U$ b/c the pressure increases, when the fluid slows down (Bernoulli Principle)

→ $v_U > 2v_T$ b/c $v_U = 4v_T$ due to Continuity: $v_U A_U = v_T A_T$ and $A_T = 4A_U$ b/c $d_T = 2d_U$ (Circle area: $A = \pi r^2 = \frac{\pi d^2}{4}$)

$\boxed{4\ pt}$ A truck horn emits a sound with a frequency of 240 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 226 Hz, then what is the speed of the truck? Use 340 m/s for the speed of the sound.
(in m/s*)*

32. A◯ 4.76 B◯ 6.91 C◯ 1.00×10^{1} D◯ 1.45×10^{1}
E◯ 2.11×10^{1} F◯ 3.05×10^{1} G◯ 4.43×10^{1} H◯ 6.42×10^{1}

source : $f_s = 240\,\text{Hz}$
observed : $f_o = 226\,\text{Hz}$ } down-shift

observer : $v_o = 0\,\text{m/s}$: at rest

source : $v_s = ?$

sound : $c = 340\,\text{m/s}$

Doppler effect :

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

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

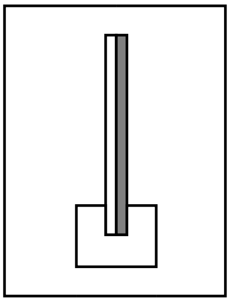
$$c f_o + v_s f_o = c f_s$$

$$v_s f_o = c f_s - c f_o$$

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

$$v_s = 340 \cdot \frac{240 - 226}{226} = 21.1\,\frac{\text{m}}{\text{s}}$$

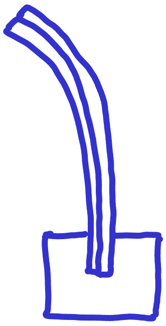
3 pt A bimetallic strip is held fixed at the bottom end as shown in the figure.



The metal on the left has a coefficient of linear heat expansion of $\alpha_{\text{left}} = 3.65 \times 10^{-5}$ 1/K, the metal on the right has $\alpha_{\text{right}} = 1.19 \times 10^{-5}$ 1/K. When the strip is cooled, it will ... (complete the sentence)

33.A◯ ... remain straight.
B◯ ... bend right.
C◯ ... bend left.

$\alpha_{\text{left}} = 3.65 \cdot 10^{-5} \frac{1}{K}$



$\alpha_{\text{right}} = 1.19 \cdot 10^{-5} \frac{1}{K}$

Since $\alpha_{\text{left}} > \alpha_{\text{right}}$, the metal on the left contracts more, when the strip is cooled. Therefore the strip will bend to the left.

4 pt A 23.2 liter gas bottle contains 4.49×10^{23} Xenon molecules at a temperature of 378 K. What is the thermal energy of the gas?
(in J*)*

34. **A**◯ 3.51×10^{3} **B**◯ 5.10×10^{3} **C**◯ 7.39×10^{3} **D**◯ 1.07×10^{4}
E◯ 1.55×10^{4} **F**◯ 2.25×10^{4} **G**◯ 3.27×10^{4} **H**◯ 4.74×10^{4}

$N = 4.49 \cdot 10^{23}$

$T = 378$ K

Xenon : $f = 3$ (single atom molecule noble gas)

$$U = \frac{f}{2} N k_B T$$

$$U = \frac{3}{2} \cdot 4.49 \cdot 10^{23} \cdot 1.38 \cdot 10^{-23} \cdot 378$$

$U = 3513$ J

$\boxed{4\ pt}$ What is the temperature of 1.08 moles of Nitrogen gas inside a 6.16 liter container, if the pressure of the gas is 10.5 atm?
(in K*)*

35. **A**◯ 243.3 **B**◯ 284.6 **C**◯ 333.0 **D**◯ 389.6
E◯ 455.8 **F**◯ 533.3 **G**◯ 624.0 **H**◯ 730.1

$n = 1.08\ \text{mol}$ $R = 8.31\ \frac{J}{\text{molK}}$

$V = 6.16\ \ell = 0.00616\ \ell$

$p = 10.5\ \text{atm} = 1.064 \cdot 10^6\ \text{Pa}$

Ideal gas law: $pV = nRT$

$$T = \frac{pV}{nR}$$

$$T = \frac{1.064 \cdot 10^6 \cdot 0.00616}{1.08 \cdot 8.31} = 730\,K$$

$\boxed{4\ pt}$ An ideal heat-engine is to be used in an environment where the ambient temperature is 32.5 °C. What should be the minimum temperature of the hot heat reservoir in order to reach at least 41.2 percent efficiency with the heat-engine? (Give your answer in Celsius.)

36. **A**◯ 1.70×10^2 **B**◯ 2.47×10^2 **C**◯ 3.58×10^2 **D**◯ 5.18×10^2
E◯ 7.52×10^2 **F**◯ 1.09×10^3 **G**◯ 1.58×10^3 **H**◯ 2.29×10^3

$\eta = 41.2\% = 0.412$

$T_c = 32.5°C = 305.5\,K$

Heat engine efficiency:

$$\eta = \frac{T_H - T_c}{T_H}$$

$$\eta T_H = T_H - T_c$$

$$T_c = T_H - \eta T_H$$

$$\frac{T_c}{1-\eta} = T_H$$

$$T_H = \frac{305.5}{1-0.412} = 519.6\,K = 246.6°C$$