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!

Possibly useful constants:

- \( g = 9.81 \text{ m/s}^2 \)
- \( G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2 \)
- \( \rho_{\text{water}} = 1 \text{ kg/l} = 1000 \text{ kg/m}^3 \)
- 1 atm = 101.3 kPa = 101,300 Pa
- \( N_A = 6.02 \times 10^{23} \text{ 1/mol} \)
- \( R = 8.31 \text{ J/molK} \)
- \( k_B = 1.38 \times 10^{-23} \text{ J/K} \)
- \( c_{\text{water}} = 4.1868 \text{ kJ/kg}^\circ C = 1 \text{ kcal/kg}^\circ C \)
- 1 cal = 4.1868 J
- \( \sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4 \)
- \( b = 2.90 \times 10^{-3} \text{ m K} \)

Possibly 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: \( I = (1/3)ML^2 \)
Please, sit in row:

Thank you!

1 pt  Are you sitting in the row assigned?

1. A  Yes, I am.

2 pt  An apple, a brick and a hammer are all dropped from the second floor of a building. Which object(s) will hit the ground first?

2. A  The apple will hit first.
   B  The brick will hit first.
   C  The hammer will hit first.
   D  The apple and the brick will hit the ground first in a tie.
   E  The brick and the hammer will hit the ground first in a tie.
   F  The hammer and the apple will hit the ground first in a tie.
   G  They all hit the ground at the same time.
   H  Without knowing the masses of the objects, we cannot tell which one hits the ground first.

Galileo Galilei: All compact and dense objects (no feathers, no leaves) fall together.

Newton: \[ F_{\text{net}} = ma \]

\[ a = \frac{F_{\text{net}}}{m} = \frac{mg}{m} = g \]

(But this cancellation is the biggest puzzle in the Universe: the mass in the numerator is the gravitational mass, the mass in the denominator is the
inertial mass. Experiments say they are the same or directly proportional to each other, but we don't understand why.)
The graph shows the speed of a car as a function of time.

\[ \text{grid intersection} \]

\[ t_1 \quad t_2 \]

2 pt Initially the car is at rest. What is the acceleration of the car? Please, note that the graph goes through at least one grid intersection point.

\( \text{(in m/s}^2) \)

3. A 0.7729  B 1.121  C 1.625  D 2.356  E 3.417  F 4.954  G 7.183  H 10.42

2 pt How much distance does the car cover between \( t_1 = 2.15 \) s and \( t_2 = 5.55 \) s?

\( \text{(in m)} \)


\[ \text{acceleration} = \frac{\text{change in velocity}}{\text{change in time}} \]

\[ a = \frac{\Delta v}{\Delta t} = \frac{13 \text{ m/s}}{8 \text{ s}} = 1.625 \text{ m/s}^2 \]

\[ \text{distance travelled is the area under the velocity versus time diagram.} \]

\[ d = \frac{v_1 + v_2}{2} \cdot \Delta t = \frac{at_1 + at_2}{2} \cdot (t_2 - t_1) = \]
\[
= \frac{1}{2} a (t_2 + t_1) (t_2 - t_1) = \frac{1}{2} a (t_2^2 - t_1^2) = \\
= d_2 - d_1 \\
d = \frac{1}{2} \cdot 1.625 \cdot (5.55^2 - 2.15^2) = 21.27 \text{m}
\]
A baseball is projected horizontally with an initial speed of 8.95 m/s from a height of 1.87 m. What is the speed of the baseball when it hits the ground? (Neglect air friction.)

$\text{的速度} = \sqrt{2gh}$ (from kinematics)

$\text{速度}^2 = 2gh$ (energy: $\frac{1}{2}mv^2 = mgh$

$\text{速度} = \sqrt{\text{速度}_x^2 + \text{速度}_0^2}$ (Pythagorean theorem)

$\text{速度} = \sqrt{2gh + \text{速度}_0^2} = \sqrt{2 \cdot 9.81 \cdot 1.87 + 8.95^2}$

$\text{速度} = 10.81 \text{ m/s}$
Two forces $\mathbf{F}_1 = -7.70 \mathbf{i} + 3.30 \mathbf{j}$ and $\mathbf{F}_2 = 6.60 \mathbf{i} + 4.60 \mathbf{j}$ are acting on a mass of $m = 6.00$ kg. The forces are measured in newtons. What is the magnitude of the object’s acceleration? (in m/s$^2$)

\[ F_{\text{net}} = \sqrt{(-1.10)^2 + (7.90)^2} = 7.98 \text{ N} \]

\[ a = \frac{F_{\text{net}}}{m} = 1.33 \text{ m/s}^2 \]
Two masses, $m_1 = 2.45$ kg and $m_2 = 8.08$ kg are on a horizontal frictionless surface and they are connected together with a rope as shown in the figure.

The rope will snap if the tension in it exceeds 60.0 N. What is the maximum value of the force $F$ which can be applied?

(in N)

7. $A$ $1.10 \times 10^2$  $B$ $1.46 \times 10^2$  $C$ $1.94 \times 10^2$  $D$ $2.58 \times 10^2$
   $E$ $3.43 \times 10^2$  $F$ $4.56 \times 10^2$  $G$ $6.07 \times 10^2$  $H$ $8.07 \times 10^2$

What is the acceleration of the whole system, when this maximum force is applied?

(in m/s$^2$)

8. $A$ $1.69 \times 10^1$  $B$ $2.45 \times 10^1$  $C$ $3.55 \times 10^1$  $D$ $5.15 \times 10^1$
   $E$ $7.47 \times 10^1$  $F$ $1.08 \times 10^2$  $G$ $1.57 \times 10^2$  $H$ $2.28 \times 10^2$

When the tension in the rope is maxed out, we have maximum acceleration: $a_{\text{max}} = \frac{T_{\text{max}}}{m_1} = \frac{60 \text{ N}}{2.45 \text{ kg}}$

$a_{\text{max}} = 24.5 \text{ m/s}^2$ (about 2.5g)

Newton's second law for the composite system at maximum acceleration:

$F_{\text{max}} = (m_1 + m_2) \cdot a_{\text{max}} = (2.45 + 8.08) \cdot 24.5$

$F_{\text{max}} = 258 \text{ N}$
An athlete, swimming at a constant speed, covers a distance of 135 m in a time period of 2.05 minutes. The drag force exerted by the water on the swimmer is 56.0 N. Calculate the power the swimmer must provide in overcoming that force.

(\text{in W})

9. \begin{align*}
\text{A} & : 4.62 \times 10^1 \\
\text{B} & : 6.15 \times 10^1 \\
\text{C} & : 8.17 \times 10^1 \\
\text{D} & : 1.09 \times 10^2 \\
\text{E} & : 1.45 \times 10^2 \\
\text{F} & : 1.92 \times 10^2 \\
\text{G} & : 2.56 \times 10^2 \\
\text{H} & : 3.40 \times 10^2
\end{align*}

Work: \quad W = \vec{F} \cdot \vec{d}

Power: \quad P = \vec{F} \cdot \vec{v}

P = F \cdot \frac{d}{t} = 56 \text{N} \cdot \frac{135 \text{m}}{2.05 \text{min} \cdot 60 \frac{\text{m}}{\text{min}}} = 61.5 \text{W}
A block with a weight of 694 N is pulled up at a constant speed on a very smooth ramp by a constant force. The angle of the ramp with respect to the horizontal is $\theta = 27.0^\circ$ and the length of the ramp is $l = 13.7$ m.

\[ wt \quad l \quad \theta \]

10. Calculate the work done by the force in pulling the block all the way to the top of the ramp. (Neglect friction.)

\[ \text{(in J)} \]

\[ \begin{array}{cccc}
\text{A} & 3.38 \times 10^3 \\
\text{B} & 3.82 \times 10^3 \\
\text{C} & 4.32 \times 10^3 \\
\text{D} & 4.88 \times 10^3 \\
\text{E} & 5.51 \times 10^3 \\
\text{F} & 6.23 \times 10^3 \\
\text{G} & 7.04 \times 10^3 \\
\text{H} & 7.95 \times 10^3 \\
\end{array} \]

\[
\text{weight} = mg = 694 \text{N} \\
\text{parallel component of the weight on an incline: } F_\parallel = mg \cdot \sin \theta \\
\text{work} = \text{force times displacement} \\
W = F_\parallel \cdot l = mg \cdot \sin \theta \cdot \frac{l}{h} : \text{height} \\
W = 694 \text{N} \cdot \sin 27^\circ \cdot 13.7 \text{m} \\
W = 4316 \text{N}
\]
A railroad cart with a mass of $m_1 = 12.6$ t is at rest at the top of an $h = 13.8$ m high hump yard hill. After it is pushed very slowly over the edge, it starts to roll down. At the bottom it hits another cart originally at rest with a mass of $m_2 = 24.3$ t. The bumper mechanism locks the two carts together. What is the final common speed of the two carts? (Neglect losses due to rolling friction of the carts. The letter t stands for metric ton in the SI system.)

\[ \text{(in m/s)} \]

\[
m_1 \text{ rolling down : conservation of energy : } \quad m_1 gh = \frac{1}{2} m v_1^2 \quad \Rightarrow \quad v_1 = \sqrt{2gh}
\]

\[
collision \text{ between } m_1 \text{ and } m_2 : \quad \text{conservation of momentum : }
\]

\[
m_1 \cdot v_1 + m_2 \cdot 0 = (m_1 + m_2) \cdot v_f
\]

\[
\frac{m_1}{m_1 + m_2} \cdot v_1 = v_f
\]

\[
v_f = \frac{12.6 \text{ t}}{12.6 \text{ t} + 24.3 \text{ t}} \cdot \sqrt{2 \cdot 9.81 \cdot 13.8}
\]

\[
v_f = 5.62 \text{ m/s}
\]

\[(1 \text{ t} = 1000 \text{ kg}, \text{ but we didn't need it.})\]
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:

\[ x(t) = A \sin(\omega t), \]

where \( x \) and \( A \) are measured in meters, \( t \) is measured in seconds, \( \omega \) is measured in rad/s.

### Question 12

**2 pt** Using the graph determine the amplitude \( A \) of the oscillation.

\( (\text{in m}) \)

12. A. 1.80 \hspace{1cm} B. 2.10 \hspace{1cm} C. 2.40 \hspace{1cm} D. 3.90 \hspace{1cm} E. 4.50 \hspace{1cm} F. 4.80 \hspace{1cm} G. 5.10 \hspace{1cm} H. 5.40

### Question 13

**2 pt** Determine the period \( T \) of the oscillation.

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

13. A. 2.80 \hspace{1cm} B. 3.20 \hspace{1cm} C. 4.00 \hspace{1cm} D. 4.40 \hspace{1cm} E. 5.20 \hspace{1cm} F. 6.80 \hspace{1cm} G. 7.60 \hspace{1cm} H. 8.00
A small mass $M$ attached to a string slides in a circle (x) on a frictionless horizontal table, with the force $F$ providing the necessary tension (see figure). The force is then increased slowly and then maintained constant when $M$ travels around in circle (y). The radius of circle (x) is twice the radius of circle (y).

\[ 10 \text{ pt} \]

\[ F \]

\[ x \quad y \]

\[ M \]

\[ 14. \text{ A} \quad \text{true} \quad \text{B} \quad \text{false} \quad \text{C} \quad \text{greater than} \quad \text{D} \quad \text{less than} \quad \text{E} \quad \text{equal to} \]

\( M \)'s kinetic energy at y is four times that at x.

\[ 15. \text{ A} \quad \text{true} \quad \text{B} \quad \text{false} \quad \text{C} \quad \text{greater than} \quad \text{D} \quad \text{less than} \quad \text{E} \quad \text{equal to} \]

\( M \)'s angular velocity at x is half that at y.

\[ 16. \text{ A} \quad \text{true} \quad \text{B} \quad \text{false} \quad \text{C} \quad \text{greater than} \quad \text{D} \quad \text{less than} \quad \text{E} \quad \text{equal to} \]

\( M \)'s angular momentum at x is .... that at y.

\[ 17. \text{ A} \quad \text{true} \quad \text{B} \quad \text{false} \quad \text{C} \quad \text{greater than} \quad \text{D} \quad \text{less than} \quad \text{E} \quad \text{equal to} \]

While going from x to y, there is a torque on M.

\[ 18. \text{ A} \quad \text{true} \quad \text{B} \quad \text{false} \quad \text{C} \quad \text{greater than} \quad \text{D} \quad \text{less than} \quad \text{E} \quad \text{equal to} \]

As M moves from x to y, the work done by $F$ is .... 0.

\[ \text{Torque: } \tau=0 \text{ because the tension in a rope is central. Central forces cannot apply torque.} \]

\[ \text{Angular momentum } L \text{ is constant, b/c the torque is zero.} \]

\[ \text{The work is positive, when the rope pulls the object in.} \]

\[ \omega_y = 4\omega_x \text{ because } L_y = L_x \text{ and } L=I\omega \]

\[ I = mr^2 : m r_x^2 \omega_y = m r_x^2 \omega_x \]

\[ KE_y=4KE_x \text{ because } KE=\frac{1}{2}I\omega^2 \text{ and } I=mr^2 \]

\[ \text{or } KE = \frac{L^2}{2I} \]
A body (not shown) has its center of mass (CM) at the origin. In each case below give the direction for the torque $\tau$ with respect to the CM on the body due to force $F$ acting on the body at a location indicated by the vector $r$. 

$\tau = r \times F$
A 275 kg satellite is orbiting on a circular orbit 5240 km above the Earth’s surface. Determine the speed of the satellite. (The mass of the Earth is $5.97 \times 10^{24}$ kg, and the radius of the Earth is 6370 km.)

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

22. A $5.86$ B $6.62$ C $7.48$ D $8.45$

E $9.55$ F $1.08 \times 10^1$ G $1.22 \times 10^1$ H $1.38 \times 10^1$

Radius of the orbit:
\[ r = R + h \]
\[ v = \sqrt{\frac{GM}{r}} \]

\[ v = \sqrt{\frac{6.67 \times 10^{-11} \cdot 5.97 \times 10^{24}}{(6370 + 5240) \cdot 1000}} \]

\[ v = 5856 \text{ m/s} \approx 5.86 \text{ km/s} \]
An object weighs 64.7 N in air. When it is suspended from a force scale and completely immersed in water the scale reads 23.4 N. Determine the density of the object. 

(in kg/m³)

\[ T_1 = mg \]
\[ T_2 = mg - B \]
\[ \frac{T_2}{T_1 - T_2} = \frac{m_{\text{fluid}} \cdot g}{m_{\text{obj}} \cdot g} \]
\[ s_{\text{fluid}} \cdot V_{\text{obj}} \cdot g = T_1 - T_2 \]
\[ s_{\text{fluid}} \cdot \frac{m_{\text{obj}} \cdot g}{s_{\text{obj}}} = T_1 - T_2 \]
\[ \frac{s_{\text{fluid}}}{s_{\text{obj}}} \cdot T_1 = T_1 - T_2 \]
\[ s_{\text{fluid}} \cdot \frac{T_1}{T_1 - T_2} = s_{\text{obj}} \]

\[ s_{\text{obj}} = 1000 \frac{\text{kg}}{\text{m}^3} \cdot \frac{64.7}{64.7 - 23.4} = 1566 \frac{\text{kg}}{\text{m}^3} \]
A large ice cube floats in a glass of water. (See figure.)

What happens to the water level, when the ice cube melts? (No water is lost due to evaporation.)

24. A. The water level will rise.
   B. It depends on how much water we have in the glass, and how big the ice cube is.
   C. The water level will not change.
   D. The water level will fall.

A 1 kg ice block displaces 1 kg water. When the 1 kg ice block melts, it gives you 1 kg water which displaces 1 kg of water.
The figure illustrates the flow of an ideal fluid through a pipe of circular cross section, with diameters of 1 cm and 2 cm and with different elevations. \( p_x \) is the pressure in the pipe, and \( v_x \) is the speed of the fluid at locations \( x = q, r, s, t, \) or \( u \). 

\[ \frac{1}{2} s v^2 + g y + p = \text{const.} \]

**Bernoulli principle:**

**Continuity:**

\[ A_1 v_1 = A_2 v_2 \]

**Cross sectional area:**

\[ A = \pi r^2 = \pi \frac{d^2}{4}; \quad d = 2r \]

When you climb up, the pressure drops: 
\( g y \) increases, therefore \( p \) drops.

When you dive, the pressure increases: 
\( g y \) decreases, therefore \( p \) increases.

When you speed up, the pressure drops: 
\( \frac{1}{2} s v^2 \) increases, therefore \( p \) decreases.

When you slow down, the pressure increases: 
\( \frac{1}{2} s v^2 \) decreases, therefore \( p \) increases.
A truck horn emits a sound with a frequency of 229 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 254 Hz, then what is the speed of the truck? Use 340 m/s for the speed of the sound.

\[ f_o = 254 \text{ Hz} \]

\[ f_s = 229 \text{ Hz} \]

It is an up-shift.

Doppler-effect:

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

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

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

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

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

\[ v_s = 340 \cdot \frac{254 - 229}{254} = 33.5 \text{ m/s} \]
Two sounds have intensities of $4.20 \times 10^{-8}$ and $6.40 \times 10^{-4}$ W/m$^2$ respectively. What is the magnitude of the sound level difference between them in dB units?

\[
\Delta \beta (\text{dB}) = 10 \log \left( \frac{I_2}{I_1} \right) = 10 \log \left( \frac{6.40 \times 10^{-4}}{4.20 \times 10^{-8}} \right) = 10 \cdot 4.183 = 41.83 \text{ dB}
\]
A hot (800 K) and a cold (200 K) heat reservoirs are connected to each other by two identical aluminum bars in two different ways as shown in the figure.

\[ P = k \cdot \frac{A}{L} \cdot \Delta T \]

Compared to the left configuration, the rate of heat transfer in the right configuration is ..... as high. (Complete the sentence.)

31. A○ one third  
   B○ three times  
   C○ four times  
   D○ one fourth  
   E○ one half  
   F○ twice

Consider the configuration shown in the figure.

Lowering the temperature of the hot reservoir from 800 K to 400 K will reduce the rate of the heat transfer by a factor of ..... (Complete the sentence.)

32. A○ three  
   B○ four  
   C○ two

because \( \Delta T \) goes from 600K to 200K
What is the pressure of 1.46 moles of Nitrogen gas in a 7.71 liter container, if the temperature of the gas is 41.0 °C?

(in atm)

Ideal Gas Law:

\[ PV = nRT \]

\[ p = \frac{nRT}{V} = \frac{1.46 \cdot 8.31 \cdot (41 + 273)}{0.00771} \]

\[ p = 4.94 \times 10^5 \text{ Pa} = 4.88 \text{ atm} \]
10 pt

Constant amount of ideal gas is kept inside a cylinder by a piston. Then the gas expands adiabatically. Compare the initial (i) and the final (f) physical quantities of the gas to each other.

34. The temperature $T_f$ is ... $T_i$.  
   - $A$ equal to
   - $B$ less than
   - $C$ greater than
   \[ b/c \text{ we are crossing isotherms} \]

35. The internal energy $U_f$ is ... $U_i$.  
   - $A$ equal to
   - $B$ less than
   - $C$ greater than
   \[ b/c \ U = \frac{1}{2} nRT \]

36. The volume $V_f$ is ... $V_i$.  
   - $A$ equal to
   - $B$ less than
   - $C$ greater than
   \[ b/c \text{ it is expansion} \]

37. The pressure $p_f$ is ... $p_i$.  
   - $A$ equal to
   - $B$ less than
   - $C$ greater than
   \[ b/c \text{ no heat is transferred} \]

38. The entropy $S_f$ is ... $S_i$.  
   - $A$ equal to
   - $B$ less than
   - $C$ greater than
An ideal heat engine has an efficiency of 15.1 percent. It operates between two heat reservoirs differing in temperature by 72.8°C. What is the temperature of the hot reservoir?

(in K)

39. A 1.58 × 10² B 2.29 × 10² C 3.32 × 10² D 4.82 × 10²
   E 6.99 × 10² F 1.01 × 10³ G 1.47 × 10³ H 2.13 × 10³

Heat engine efficiency à la Carnot:

\[ \eta = \frac{T_H - T_C}{T_H} \]

\[ \eta = \frac{\Delta T}{T_H} \Rightarrow T_H = \frac{\Delta T}{\eta} = \frac{72.8}{0.151} = 482 \text{ K} \]