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1. Use a #2 pencil to make entries on the answer sheet. Enter the following ID information now, before the exam starts.
2. In the section labeled NAME (Last, First, M.I.) enter your last name, then fill in the empty circle for a blank, then enter your first name, another blank, and finally your middle initial.
3. Under STUDENT # enter your 9-digit RUID Number.
4. Under CODE enter the exam code given above.
5. Enter 124 under COURSE. You do not need to write anything else on the answer sheet. You should continue to read the instructions.
6. During the exam, you are allowed three 8.5 x 11 inch sheets of paper handwritten, both sides.
7. The exam consists of 30 multiple-choice questions. For each multiple-choice question mark only ONE answer. There is no deduction of points for an incorrect answer; if you cannot work out the answer to a question, you should make an educated guess.
8. If you have questions or problems during the exam, you may raise your hand and a proctor will assist you. We will provide the value of physical constants that are needed. It is your responsibility to know the relevant equations.
9. A proctor will check your name sticker and your student ID sometime during the exam. Please have them ready.
10. You are not allowed to help any other student, ask for help from anyone but a proctor, change your seat without permission from a proctor or use any electronic device other than a scientific calculator. Doing so will result in a zero score for the exam.
11. When you are done with the exam, hand in only this cover sheet and your answer sheet.
12. Please SIGN above by the name sticker to indicate that you have read and understood these instructions.
Possibly useful constants:
\( G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \)
\( g = 9.8 \text{ m/s}^2 \)
Radius of Earth = \( 6.4 \times 10^6 \) m, mass of Earth = \( 6.0 \times 10^{24} \) kg
Speed of sound in air at 20\(^\circ\)C: \( v_{\text{sound}} = 344 \) m/s
Density of water = \( 10^3 \) kg/m\(^3\), 1 atm = \( 1.01 \times 10^5 \) Pa,
Density of air = \( 1.2 \) kg/m\(^3\)
Specific heat of water = 1 cal/(g °C)
Gas constant \( R = 8.314 \) J/mol K
Boltzmann constant \( k_B = 1.38 \times 10^{-23} \) J/K
Stefan-Boltzmann constant \( \sigma = 5.67 \times 10^{-8} \) W/m\(^2\)K\(^4\)
Avogadro’s number is \( R/k_B = 6.02 \times 10^{23} \) molecules/mol
0\(^\circ\)C = 273 K
Mechanical equivalent of heat = 4.186 J/cal

Moments of inertia for uniform density objects:
\( I_{\text{disk}} = I_{\text{solid cylinder}} = \frac{1}{2} MR^2 \)
\( I_{\text{thin walled hollow cylinder}} = I_{\text{ring}} = MR^2 \)
\( I_{\text{solid sphere}} = \frac{2}{5} MR^2, I_{\text{thin walled hollow sphere}} = \frac{2}{3} MR^2 \)
\( I_{\text{slender rod, axis through center}} = \frac{1}{12} ML^2 \)
\( I_{\text{slender rod, axis through one end}} = \frac{1}{3} ML^2 \)

Circumference of a circle = \( 2\pi r \); area of a circle = \( \pi r^2 \)
Surface area of a sphere = \( 4\pi r^2 \); Volume of a sphere = \( \frac{4}{3} \pi r^3 \)
Surface area of a cylinder = \( 2\pi rh + 2\pi r^2 \)
Volume of cylinder = \( \pi r^2 h \)

\( \sin(0^\circ) = \cos(90^\circ) = 0 \)
\( \sin(90^\circ) = \cos(0^\circ) = 1 \)
\( \sin(30^\circ) = \cos(60^\circ) = \frac{1}{2} \)
\( \sin(60^\circ) = \cos(30^\circ) = \frac{\sqrt{3}}{2} \)
\( \sin(45^\circ) = \cos(45^\circ) = \frac{\sqrt{2}}{2} \)
\( \frac{dx^n}{dx} = nx^{n-1} \)
\( \int x^n = \frac{1}{n+1}x^{n+1} \) except when \( n = -1 \). For \( n = -1 \), \( \int dx/x = \ln x \)

Some metric prefixes:
f = femto = \( 10^{-15} \)
p = pico = \( 10^{-12} \)
n = nano = \( 10^{-9} \)
1. A wooden raft has a mass of 70 kg. When empty it floats in water (density 1000 kg/m³) with 1/3 of its volume submerged. What is the maximum mass \( m \) of sand that can be put on the raft without it sinking?

   - a) \( m = 140 \text{ kg} \)
   - b) \( m = 70 \text{ kg} \)
   - c) \( m = 210 \text{ kg} \)
   - d) \( m = 35 \text{ kg} \)
   - e) \( m = 280 \text{ kg} \)

2. In a pipe of radius \( r_1 = 0.1 \text{ m} \), the water flow is \( v_1 = 3 \text{ m/s} \) past a certain point. What is the speed of the water \( v_2 \) further along the pipe where it expands to a radius \( r_2 = 0.12 \text{ m} \)?

   - a) \( v_2 = 2.1 \text{ m/s} \)
   - b) \( v_2 = 1.7 \text{ m/s} \)
   - c) \( v_2 = 1.4 \text{ m/s} \)
   - d) \( v_2 = 2.4 \text{ m/s} \)
   - e) \( v_2 = 2.9 \text{ m/s} \)

3. Cylinders with equal cross-sectional areas contain different volumes of the same ideal gas sealed in by pistons. The pistons are free to move without friction. The temperature is the same in all of the figures. Rank the number of moles of the gas in each of the cylinders.

   - a) \( A > B = D > C \)
   - b) \( A > B > C > D \)
   - c) \( A > D > B > C \)
   - d) \( A = D > B = C \)
   - e) \( A = B = C = D \)
4. Referring to the $p-V$ plot in the figure, calculate the work $W$ done by the gas during the process $1 \rightarrow 3 \rightarrow 6 \rightarrow 2 \rightarrow 1$.

\[ W = \frac{1}{2} (3V_0 - V_0) (p_0 - 3p_0) = -2p_0 V_0 \]

5. Which of the following is TRUE?
   a) Within a system, there can be heat transfer without entropy change. **FALSE**
   b) The Carnot cycle is the least efficient cycle possible. **FALSE**
   c) Even idealized adiabatic processes are irreversible. **FALSE**
   d) Perpetual motion machines can violate the first or second laws of thermodynamics, but not both. **FALSE**
   e) For a refrigerator, the coefficient of performance becomes larger as the heat transfer between hot and cold reservoirs becomes smaller. **TRUE**

6. The First Law of Thermodynamics is based on which concept?
   a) Conservation of energy
   b) Conservation of momentum
   c) Increase of entropy for irreversible processes
   d) Loss of energy to friction
   e) Thermal equilibrium

7. The figure displays a mobile. The numbers in the figure represent the relative length of the rods on either side of the supporting cords. Object $A$ has mass $m_A = 1.0$ kg. For the entire mobile to be balanced, what is the mass $m_B$ of object $B$?

\[ \sum \tau = 0 \text{ at every pivot} \]

\[ 2 \times \tau = 0 \]

\[ \begin{align*}
   &3(B) = 4.5(1) \\
   &B = 4.5 \\
   &3 \times \tau = 0 \\
   &2(1) = 1(1) \\
   &2 \times \tau = 0 \\
   &2(1) = 1(1) \\
   &2 \times \tau = 0 \\
   &2 \times \tau = 0 \\
\end{align*} \]

a) $m_B = 1.0$ kg  
 b) $m_B = 1.5$ kg  
 c) $m_B = 2.0$ kg  
 d) $m_B = 0.5$ kg  
 e) $m_B = 0.67$ kg

8. A simple pendulum has a period of $T_E = 2.0$ s. What is the approximate period $T_M$ of this pendulum on the surface of Mars, where $g_{Mars} = 3.7$ m/s$^2$?

\[ T = \sqrt{\frac{g}{3}} \]

\[ T = \sqrt{\frac{3.7}{3}} \]

a) $T_M = 2.0$ s  
 b) $T_M = 2.6$ s  
 c) $T_M = 3.3$ s  
 d) $T_M = 5.3$ s  
 e) Need to know the length of the pendulum.

9. A cube 0.05 m on each side is made of a metal alloy. After you drill a cylindrical hole 0.02 m in diameter all the way through and perpendicular to one face, you find that the cube weighs 8.0 N. What is the density $\rho$ of this metal, to 2 significant figures?

\[ \rho = \frac{m}{V} \]

\[ m = \frac{8.0 \text{ N} \cdot 0.02 \text{ m}^2}{9.8 \text{ m/s}^2} \]

\[ \rho = \frac{8.0 \text{ N} \cdot 0.02 \text{ m}^2}{9.8 \text{ m/s}^2} \]

\[ \rho = \frac{8.0 \text{ N} \cdot 0.02 \text{ m}^2}{9.8 \text{ m/s}^2} \]

a) $\rho = 6500$ kg/m$^3$  
 b) $\rho = 7500$ kg/m$^3$  
 c) $\rho = 73,000$ kg/m$^3$  
 d) $\rho = 64,000$ kg/m$^3$  
 e) $\rho = 750$ kg/m$^3$
10. One spring day in New Jersey the numerical value of the temperature in Fahrenheit was 50 more than the numerical value of the temperature in Celsius. What was the temperature in Fahrenheit \( T_F \) that day? Choose the closest answer from the options given below.

   a) \( T_F = 40 \degree F \)
   b) \( T_F = 50 \degree F \)
   c) \( T_F = 60 \degree F \)
   d) \( T_F = 70 \degree F \)
   e) \( T_F = 80 \degree F \)

11. A 5.0-liter gas tank holds 2.6 moles of monatomic helium (He) and 1.30 moles of monatomic neon (Ne), at a temperature of 310 K. The molar masses of helium and neon are 4.0 g/mol and 20.0 g/mol, respectively. What is the ratio \( R = \frac{v_{rms-He}}{v_{rms-Ne}} \) of the root-mean-square (thermal) speed of helium to that of neon?

   a) \( R = 5.0 \)
   b) \( R = 2.5 \)
   c) \( R = 1.4 \)
   d) \( R = 2.2 \)
   e) \( R = 4.0 \)

12. A cylinder contains 0.250 mol of nitrogen (N\(_2\)) gas at a temperature of 30.0 \( \degree C \). The cylinder is provided with a frictionless piston, which maintains a constant pressure of 1.00 atm = 1.0 \times 10^5 \text{ Pa} on the gas. The gas is heated until its temperature increases to 130.0 \( \degree C \). Assume that the N\(_2\) can be treated as an ideal gas. How much work \( W \) is done by the gas?

   a) \( W = -208 \text{ J} \)
   b) Cannot determine \( W \) because need to know initial volume \( V_0 \).
   c) \( W = +516 \text{ J} \)
   d) \( W = +208 \text{ J} \)
   e) \( W = -837 \text{ J} \)

13. The figure displays a design for an engine. What is the efficiency \( \epsilon \) of this engine?

   a) The efficiency cannot be calculated because this engine violates the first law of thermodynamics.
   b) \( \epsilon = 40\% \)
   c) \( \epsilon = 60\% \)
   d) \( \epsilon = 38\% \)
   e) \( \epsilon = 63\% \)

14. Three moles of an ideal gas undergo a reversible isothermal compression at a temperature of 20 \( \degree C \). During this compression, an amount of work totalling 1800 J is done ON the gas. What is the change in entropy \( \Delta S \) of the gas?

   a) \( \Delta S = -6.14 \text{ J/K} \)
   b) \( \Delta S = +90.0 \text{ J/K} \)
   c) \( \Delta S = +6.14 \text{ J/K} \)
   d) Need to know the amount of heat that enters the system.
   e) \( \Delta S = -90.0 \text{ J/K} \)

\[
\Delta S = \frac{\Delta Q}{T} = -\frac{\Delta W}{T} = \frac{1800 \text{ J}}{(273+20)} = -6.14 \text{ J/K}
\]
15. In the figure, which of the curves best represents the variation of the wave speed as a function of tension for transverse waves on a stretched string?

\[ v = \sqrt{\frac{T}{\mu}} \]

a) Curve E  
b) Curve A  
c) Curve D  
d) Curve B  
e) Curve C

17. Which of the following statements about Archimedes principle is TRUE?
I. The magnitude of the buoyant force is equal to the weight of fluid displaced by the object, for every object submerged partially or completely in a fluid.  **TRUE**
II. The magnitude of the buoyant force is equal to the weight of the amount of fluid that has the same total volume as the object, for an object that is partially submerged in a fluid.  **FALSE**
III. The magnitude of the buoyant force equals the weight of the object, for an object that floats.  **TRUE**
IV. The magnitude of the buoyant force is less than the weight of the object, for an object that sinks.  **TRUE**

a) All statements are TRUE.  
b) Statements I, III, and IV are TRUE. Statement II is FALSE.  
c) Statements I, and IV are TRUE. Statements II and III are FALSE.  
d) Only Statement I is TRUE. Statements II, III, and IV are FALSE.  
e) Statements I, and III are TRUE. Statements II and IV are FALSE.

16. A person is hearing two sound waves simultaneously. One has a period of \( T_1 = 1.50 \text{ ms} \) and the other one has a period of \( T_2 = 1.54 \text{ ms} \). What is the period \( T_B \) of the beat due to these two waves?

\[ T_B = \frac{1}{\frac{1}{T_1} - \frac{1}{T_2}} = \frac{1}{\frac{1}{1.50 \times 10^{-3}} - \frac{1}{1.54 \times 10^{-3}}} \approx 58 \text{ ms} \]

a) \( T_B = 3.0 \text{ ms} \)  
b) \( T_B = 1.5 \text{ ms} \)  
c) \( T_B = 58 \text{ ms} \)  
d) \( T_B = 25 \text{ ms} \)  
e) \( T_B = 0.040 \text{ ms} \)

18. Water has a latent heat of fusion of \( 334 \times 10^3 \text{ J/kg} \), a latent heat of vaporization of \( 2256 \times 10^3 \text{ J/kg} \), and a specific heat of about \( 4186 \text{ J/kg-K} \). When you mix 400 g of ice at 0 °C with 100 g of steam at 100 °C, what do you end up with?

a) Pure steam at 100 °C  
b) A steam-water mix at 100 °C  
c) Water at some temperature between 0 °C and 100 °C  
d) An ice-water mix at 0 °C  
e) Pure ice at 0 °C
19. You are given \( m = 1 \) kg each of four coolants (Alpha, Beta, Gamma and Delta) and have been asked to rank their heat capacities. Your measurements are summarized in the following table, where the energy you add and corresponding temperature rise are given. Rank the heat capacities of the coolants from largest to smallest.

\[
Q = m \Delta T \Rightarrow C = \frac{Q}{m \Delta T} = \frac{Q}{\Delta T}
\]

<table>
<thead>
<tr>
<th>Coolant Name</th>
<th>Energy added (J)</th>
<th>Temp change (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>3,000</td>
<td>2.0</td>
</tr>
<tr>
<td>Beta</td>
<td>6,000</td>
<td>3.0</td>
</tr>
<tr>
<td>Gamma</td>
<td>10,000</td>
<td>8.0</td>
</tr>
<tr>
<td>Delta</td>
<td>9,000</td>
<td>5.0</td>
</tr>
</tbody>
</table>

20. An ideal gas system is taken from state \( a \) to state \( b \) along the three paths shown in the figure. Which of the statements describing this are TRUE?

I. The work done by the system is greatest along path 1. **TRUE**

II. If \( U_b > U_a \), the absolute value \( |Q| \) of the heat transfer is greatest along path 1. **TRUE**

III. Heat is absorbed by the system. **TRUE**

a) None of these statements is true.

b) All of these statements are true.

c) Only I and II are true; III is false.

d) Only I is true; II and III are false.

e) Only II and III are true; I is false.

21. A thermal engine is filled with \( N \) molecules of a monatomic ideal gas. The gas undergoes a cyclic transformation as displayed in the figure. Processes \( AB \) and \( CD \) are isothermal and processes \( BC \) and \( DA \) are isochoric (constant volume). For which of the processes in this cycle does heat flow INTO the gas?

a) Process \( DA \) only

b) Process \( CD \) and \( DA \) only

c) Process \( DA \) and \( AB \) only

d) Process \( AB \) and \( BC \) only

e) Process \( BC \) and \( DA \) only
22. The mean radius $R_N$ of the orbit of the planet Neptune is about 30 times the Earth's mean orbital radius $R_E$ about the Sun, i.e. $R_N = 30 R_E$. What is the approximate period $T_N$ of one orbit for Neptune?
   a) $T_N$ is about 9.7 Earth years
   b) $T_N$ is about 30 Earth years
   c) $T_N$ is about 164 Earth years
   d) $T_N$ is about 900 Earth years
   e) $T_N$ is about 5.5 Earth years

23. Two loudspeakers, $A$ and $B$, are driven by the same amplifier and emit sinusoidal waves in phase. Speaker $B$ is 2 m to the right of speaker $A$. Point $Q$ lies along the extension of the line connecting the speakers, 1 m to the right of speaker $B$. Both speakers emit sound waves that travel directly from the speaker to point $Q$. What is the lowest frequency $f$ for which destructive interference occurs at point $Q$? Note: $v_{\text{sound}} = 344$ m/s.

24. You are driving a late model convertible car at the 65 miles per hour speed limit with its soft flexible roof closed up and the windows closed. Which of the following statements is TRUE about your observation of the roof of your convertible?
   a) You observe that the roof bows inward (towards the driver).
   b) You observe that the roof bows inward (towards the driver) only when you are driving uphill.
   c) You observe that the roof bows inward (towards the driver) only when you are driving downhill.
   d) You observe that the roof is no different from when the car was at rest.
   e) You observe that the roof bows outward (away from the driver).

25. When an object with mass $m$ is supplied with heat $Q$ its temperature changes by $\Delta T_1$. Let the specific heat of the object be $c$. If the mass of the object is increased to $2m$ and $2Q$ of heat is supplied, what is now the change in its temperature $\Delta T_2$?

\[
\frac{\Delta T_2}{\Delta T_1} = \frac{Q_2}{Q_1/m} = \frac{2Q}{Q/m} = 2
\]

- a) $\Delta T_2 = \Delta T_1$
- b) $\Delta T_2 = 2\Delta T_1$
- c) $\Delta T_2 = 4\Delta T_1$
- d) $\Delta T_2 = \Delta T_1/2$
- e) $\Delta T_2 = \Delta T_1/4$

---

\[ f = \frac{n \nu}{2d} \]

\[ d = 3m - 1m = 2m \]

\[ n = \frac{f \times 2(2m)}{344m/s} = 86 \text{ Hz} \]
26. As displayed in the figure, two cylinders are filled to the same height $H$ with 6 moles of an ideal gas. The gases are different and the cross sectional areas of the cylinders are different. Both cylinders have pistons that are free to move without friction. What is the relationship of the temperature $T_B$ of cylinder $B$ and the temperature $T_A$ of cylinder $A$?

\[ \frac{P_V}{nRT} = \frac{n_B}{n_A} = \frac{P_BV_B}{P_AV_A} = \frac{(\frac{\alpha_A}{2A})(2A + h)}{(\frac{\alpha_A}{A})(A + h)} = 5 \]

27. Two moles of a monatomic ideal gas are at an initial pressure $p_0$ and volume $V_0$. The figure displays a $p-V$ diagram for a reversible cycle process 1 $\rightarrow$ 2 $\rightarrow$ 3 $\rightarrow$ 4 $\rightarrow$ 1, etc. The pressures $p_1 = p_4 = p_0$ and $p_2 = p_3 = 3p_0$, and the volume $V_2 = 2V_0$. What is the difference in temperature $\Delta T$ between the maximum $T_{\text{max}}$ and minimum $T_{\text{min}}$ temperatures?

\[ \Delta T = \frac{5p_0V_0}{2R} \]

\[ T_{\text{max}} = \left( \frac{5p_0}{2R} \right) \left( \frac{2V_0}{2R} \right) \]

\[ T_{\text{min}} = \left( \frac{p_0}{2R} \right) \left( \frac{V_0}{2R} \right) \]

\[ \Delta T = \frac{5p_0V_0}{2R} \]

28. An object at $20 \, ^\circ\text{C}$ absorbs 25.0 J of heat. What is the change in entropy $\Delta S$ of the object?

a) It depends on the latent heat of fusion of the object.

b) $\Delta S = 0.085 \, \text{J/K}$

c) $\Delta S = 1.25 \, \text{J/K}$

d) $\Delta S = 0.80 \, \text{J/K}$

e) $\Delta S = 11.7 \, \text{J/K}$

29. Derive an expression for the period $T$ of the motion experienced by an object freely falling, just using the force of gravity, from one side of the earth to the other. Variables you may need include the radius of the earth $R_E$, the mass of the earth $M_E$, and the gravitational constant $G$.

\[ T = \sqrt{\frac{GM_E}{4R_E^3}} = \frac{m}{M_E} \left( \frac{G}{R_E^2} \right)^{\frac{3}{2}} \]

30. A non-rotating record is dropped vertically onto a freely rotating (undriven) turntable. Frictional forces act to bring the record and turntable to a common angular speed. If the moment of inertia of the record is $3/4$ that of the turntable, what fraction $F$ of the initial kinetic energy is lost?

a) $F = 0$ because kinetic energy is conserved.

b) $F = 3/7$

c) $F = 1/3$

d) $F = 3/4$

e) $F = 4/7$

\[ KE_{\text{int}} = \frac{1}{2} I w^2 \]

\[ KE_{\text{lost}} = \frac{1}{2} I w^2 \left( I + \frac{3}{4} I \right) \]

\[ \Delta KE = 1 - \frac{4}{7} = \frac{3}{7} \]