Physics 124 – Final Exam
Tuesday May 9, 2017, 4:00 PM - 7:00 PM
CAC Gym Annex (Aa-Jz), CAC Gym (Ka-Sz)
and Scott (Ta-Zz)

Your exam code

SIGN HERE

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 and 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. 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. NO smart watches, NO cell phones.
10. When you are done with the exam, show your ID to a proctor and hand in only this cover sheet and your answer sheet.
11. 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 \text{ m}, mass of Earth = 6.0 \times 10^{24} \text{ kg}

Speed of sound in air at 20°C: \( v_{\text{sound}} = 344 \text{ m/s} \)
\[ \rho_{\text{water}} = 10^3 \text{ kg/m}^3; \ \rho_{\text{air}} = 1.2 \text{ kg/m}^3; \ \text{1 atm} = 1.01 \times 10^5 \text{ Pa} \]

Specific heat of water = 4190 \text{ J/kg-K}

Gas constant \( R = 8.314 \text{ J/mol-K} \)

Boltzmann constant \( k_B = 1.38 \times 10^{-23} \text{ J/K} \)

Stefan-Boltzmann constant \( \sigma = 5.67 \times 10^{-8} \text{ W/m}^2\cdot\text{K}^4 \)

Avogadro’s number is \( N = 6.02 \times 10^{23} \text{ molecules/mol} \)

0°C = 273 \text{ K}

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

\[ \sin(0^\circ) = \cos(90^\circ) = 0; \ \sin(90^\circ) = \cos(0^\circ) = 1 \]
\[ \sin(30^\circ) = \cos(60^\circ) = 1/2; \ \sin(60^\circ) = \cos(30^\circ) = \sqrt{3}/2 \]
\[ \sin(45^\circ) = \cos(45^\circ) = \sqrt{2}/2 \]
\[ \tan(30^\circ) = 1/\sqrt{3}; \ \tan(60^\circ) = \sqrt{3} \]

\[ \tan \theta = \frac{\sin \theta}{\cos \theta}; \ \cos \theta = 1/\sqrt{(1 + \tan^2 \theta)} \]

\[ \frac{dx^n}{dx} = nx^{n-1} \]
\[ \int x^n = \frac{1}{n+1}x^{n+1} \text{ except when } n = -1. \text{ For } n = -1, \int dx/x = \ln x \]
\[ \frac{d}{dx} \sin(ax) = a \cos(ax); \ \frac{d}{dx} \cos(ax) = -a \sin(ax) \]
\[ \int \sin(ax)dx = -\cos(ax)/a; \ \int \cos(ax)dx = \sin(ax)/a \]

Some metric prefixes:

f = femto = 10^{-15}
p = pico = 10^{-12}
n = nano = 10^{-9}
\( \mu \) = micro = 10^{-6}
m = milli = 10^{-3}
k = kilo = 10^3
M = mega = 10^6
G = giga = 10^9
1. A metal knife and a wooden hairbrush have been sitting on the same countertop all night. Below are three statements about this situation.
I. The hairbrush feels warmer than the knife.
II. The hairbrush is at a higher temperature than the knife.
III. The hairbrush and the knife are at the same temperature.
Which of the following is TRUE?
   a) Statements I and III are TRUE, statement II is false.
   b) Only statement I is TRUE. Statements II and III are false.
   c) Only statement III is TRUE. Statements I and II are false.
   d) None of the statements are TRUE, all are false.
   e) Statements I and II are TRUE, statement III is false.

2. The figure displays three Carnot engines operating between different hot and cold reservoirs. The heat energy transferred to the gas during the isothermal (constant temperature) expansion phase of each cycle is 1000 J as indicated. For Engine A: \( T_H = 600 \text{ K} \), \( T_C = 300 \text{ K} \). For Engine B: \( T_H = 500 \text{ K} \), \( T_C = 250 \text{ K} \). For Engine C: \( T_H = 500 \text{ K} \), \( T_C = 300 \text{ K} \). Rank these engines on the basis of the change in entropy \( \Delta S \) of the gas during the isothermal expansion phase of the cycle.

   \[
   a) \quad \Delta S_A = \Delta S_B = \Delta S_C \\
   b) \quad \Delta S_B > \Delta S_A = \Delta S_C \\
   c) \quad \Delta S_B = \Delta S_C > \Delta S_A \\
   d) \quad \Delta S_A = \Delta S_B > \Delta S_C \\
   e) \quad \Delta S_C > \Delta S_B > \Delta S_A 
   \]
3. A container is filled with a mixture of helium (light molecules) and oxygen (heavy molecules) gases. A thermometer in the container reads 20°C. Which of the following statements is TRUE?

a) The helium molecules have the greater average translational kinetic energy because they are monatomic.
b) The helium molecules have the greater average translational kinetic energy because they are less massive.
c) The oxygen molecules have the greater average translational kinetic energy because they are more massive.
d) The oxygen molecules have the greater average translational kinetic energy because they are diatomic.
e) The average translational kinetic energies of both gases is the same because the temperatures are the same.

4. Three moles of an ideal gas with a molar heat capacity at constant volume $c_V = 20 \text{ J/mol} \cdot \text{K}$ and a molar heat capacity at constant pressure $c_p = 29 \text{ J/mol} \cdot \text{K}$ starts at 300 K and is heated at constant pressure to 320 K, then cooled at constant volume to its original temperature. How much heat $\Delta Q$ flows into the gas during this two-step process?

a) $\Delta Q = 0$ because the temperature does not change.
b) $\Delta Q = -2900 \text{ J}$
c) $\Delta Q = -540 \text{ J}$
d) $\Delta Q = +540 \text{ J}$
e) $\Delta Q = -2900 \text{ J}$

5. How much heat $\Delta Q$ needs to be added to raise $n = 2$ moles of a diatomic ideal gas by $\Delta T = 40^\circ\text{C}$?

a) $\Delta Q \sim 3330 \text{ J}$
b) $\Delta Q \sim 1660 \text{ J}$
c) $\Delta Q \sim 830 \text{ J}$
d) $\Delta Q \sim 1000 \text{ J}$
e) $\Delta Q \sim 500 \text{ J}$

6. A wooden raft has a mass $M = 50 \text{ kg}$. When empty it floats in water ($\rho_{\text{water}} = 1000 \text{ kg/m}^2$) with 1/3 of its volume submerged. What mass $m$ of sand can be put on the raft without it sinking?

a) $m = 50 \text{ kg}$
b) $m = 250 \text{ kg}$
c) $m = 125 \text{ kg}$
d) $m = 150 \text{ kg}$
e) $m = 100 \text{ kg}$
7. A train is traveling relative to the ground at a speed \( v_T \) and the frequency of the note emitted by the train horn is \( f_T = 300 \) Hz. A passenger is on another train that is traveling in the opposite direction and is receding from the first train at a speed \( v_L \). If both trains are traveling at a speed of \( v_T = v_L = 25 \) m/s what is the frequency \( f_L \) heard by the passenger on the receding train? Use \( v_{\text{sound}} = 344 \) m/s.

a) \( f_L = 280 \) Hz  

b) \( f_L = 320 \) Hz  

c) \( f_L = 300 \) Hz  

d) \( f_L = 260 \) Hz  

e) \( f_L = 340 \) Hz

8. A 2.0-m long string is fixed at both ends and tightened until the wave speed \( v = 90 \) m/s. What is the frequency \( f \) of the standing wave shown in the figure?

a) \( f = 90 \) Hz  

b) \( f = 45 \) Hz  

c) \( f = 135 \) Hz  

d) \( f = 15 \) Hz  

e) \( f = 30 \) Hz

9. Bernadette puts a bottle of soft drink in a refrigerator and leaves it there until its temperature has dropped \( \Delta T = 10 \) K. What is the magnitude of the temperature change \( \Delta T \) in degrees Fahrenheit?

a) \( \Delta T = 10^\circ \) F  

b) \( \Delta T = 18^\circ \) F  

c) \( \Delta T = 5.6^\circ \) F  

d) \( \Delta T = 477^\circ \) F  

e) \( \Delta T = 157^\circ \) F
10. Which of the following statements is FALSE?
   a) To increase the efficiency of an ideal heat engine one can increase the temperature of the hot reservoir.
   b) To increase the coefficient of performance of an ideal refrigerator one can decrease the outside temperature.
   c) Every heat engine must have a cold reservoir because it is impossible for even a perfect engine to convert heat entirely into mechanical work.
   d) According to the second law of thermodynamics, it is impossible for an ideal heat engine to have non-zero power.
   e) According to the second law of thermodynamics it is impossible for an ideal heat engine to have an efficiency of 99%.

11. During an adiabatic expansion (going from state 1 to state 2) the temperature of 1 mol of argon drops from 65°C to 10°C. The argon may be treated as an ideal gas.

Which of the following figures is a correct $p - V$ diagram for this process?
   a) Graph W is the correct $p - V$ diagram.
   b) Graph Y is the correct $p - V$ diagram.
   c) Graph Z is the correct $p - V$ diagram.
   d) Graph X is the correct $p - V$ diagram.
   e) None of the diagrams are correct for an adiabatic process.

12. A real heat engine operates between temperatures $T_C$ and $T_H$. During a certain time, an amount of heat $Q_C$ is released to the cold reservoir. During that time, what is the magnitude of the maximum amount of work $|W_{max}|$ that the engine might have performed?
   a) $|W_{max}| = (T_H/T_C - 1)Q_C$
   b) $|W_{max}| = Q_C$
   c) $|W_{max}| = (1 - T_C/T_H)Q_C$
   d) $|W_{max}| = (T_H/T_C)Q_C$
   e) $|W_{max}| = Q_H$
13. As a rough approximation, the human body may be considered as a cylinder of length $L = 2.0$ m and circumference $C = 0.8$ m. (To simplify we can ignore the top and bottom of the cylinder, and just consider the cylindrical sides). If the emissivity of skin is taken to be $\epsilon = 0.6$ and the surface temperature is taken to be $T = 30^\circ$C, how much thermal power $P$ does the human body radiate? Note Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ W/m$^2$·K$^4$.

   a) $P = 4.4 \times 10^{-2}$ W
   b) $P = 770$ W
   c) $P = 460$ W
   d) $P = 302$ W
   e) $P = 7.4 \times 10^{-2}$ W

14. A satellite of mass $M$ revolves around the earth twice a day in an orbit of radius $R_1$. What should the radius $R_2$ of its orbit be if you want it to revolve around the earth four times a day?

   a) $R_2 = R_1/\sqrt{4}$
   b) $R_2 = R_1$
   c) $R_2 = 2R_1$
   d) $R_2 = R_1/2$
   e) $R_2 = R_1\sqrt{4}$
15. A hockey stick of mass $M$ and length $L$ is at rest on the ice (which is assumed to be frictionless). A puck with mass $m$ hits the stick a distance $D$ from the middle of the stick, as displayed in the Figure. Before the collision, the puck was moving with speed $v_0$ in a direction perpendicular to the stick. The collision is completely inelastic, and the puck remains attached to the stick after the collision. Which of the following statements are TRUE for the hockey stick plus puck system?

I. Kinetic energy is conserved.
II. Linear momentum is conserved.
III. Angular momentum of the stick+puck is conserved about the center of mass of the combined system.

a. Only III is true; I and II are false.
b. Only I is true; II and III are false.
c. Only II is true; I and III are false.
d. Only II and III are true; I is false.
e. I, II and III are true.
16. Two small speakers A and B are driven in step at $f = 750$ Hz by the same audio oscillator. These speakers both start out 4.50 m from the listener, but speaker A is slowly moved away from speaker B and the listener. At what distance $d$ will the sound from the speakers first produce destructive interference at the location of the listener? Use $v_{\text{sound}} = 344$ m/s.

![Diagram of two speakers A and B]

- a) $d = 0.34$ m
- b) $d = 0.23$ m
- c) $d = 0.17$ m
- d) $d = 0.69$ m
- e) $d = 0.46$ m

17. Two identical uniform solid spheres are attached by a solid uniform thin rod as shown in the Figure. The rod lies on a line connecting the centers of mass of the two spheres. The axes A, B, C, and D are in the plane of the page (which also contains the centers of mass of the spheres and the rod). Rank the moments of inertia $I$ of this object about axes A, B, C, and D.

![Diagram of spheres and rod]

- a) $I_D > I_C > I_B > I_A$
- b) $I_A > I_B > I_C > I_D$
- c) $I_A = I_C > I_B > I_D$
- d) $I_C > I_B > I_A > I_D$
- e) $I_B > I_A = I_D > I_C$
18. A $T_1 = 10 \, ^\circ\text{C}$, the average translational kinetic energy of a gas molecule is $K_1$. If the temperature is now increased to $T_2 = 100 \, ^\circ\text{C}$, what is the new average translational kinetic energy of the molecule $K_2$?
   a) $K_2 = 0.76K_1$
   b) $K_2 = 10K_1$
   c) $K_2 = 1.32K_1$
   d) None of the other answers are correct. Need to know if the gas is monatomic or diatomic.
   e) $K_2 = K_1/5$

19. Several moles of gas are compressed adiabatically. During the compression, the work done on the gas is $W = 249 \, \text{J}$. Which of the following statements is TRUE?
   a) The internal energy decreases by more than 249 J.
   b) The internal energy increases by exactly 249 J.
   c) The internal energy decreases by exactly 249 J.
   d) The expansion is adiabatic so there cannot be a temperature change.
   e) The internal energy increases by more than 249 J.
20. Ammonia is a colorless, pungent gas at standard pressure and temperature. The figure displays the phase diagram of ammonia as a function of pressure (in atm) and temperature (in K).

For transportation, ammonia is stored as a liquid under its own vapor pressure, i.e., the liquid and gas phases exist simultaneously. A container of ammonia is to be transported in a temperature-controlled truck. The container can withstand a maximum pressure $p_{\text{max}} = 6$ atm. What is the maximum temperature $T_{\text{max}}$ at which the container has to be maintained to sustain ammonia in a mixture of liquid and gas phases?

a) $T_{\text{max}} \sim 400$ K
b) $T_{\text{max}} \sim 250$ K
c) $T_{\text{max}} \sim 200$ K
d) $T_{\text{max}} \sim 300$ K
e) $T_{\text{max}} \sim 350$ K
21. In the figure a weight of mass $M$ is tied to a rope that is wrapped around a pulley of radius $R$. The pulley is initially rotating counterclockwise and is pulling the weight up. The tension in the rope creates a torque $\tau$ on the pulley that opposes this rotation. At the instant the pulley stops rotating counterclockwise and before starting to rotate clockwise, what is the angular velocity $\omega$ of the pulley about the axis of rotation?

a) $\omega = \frac{\tau}{MR}$
b) $\omega = \frac{\tau}{MR^2}$
c) $\omega = 0$
d) $\omega$ is increasing.
e) $\omega$ is decreasing.

22. As displayed in the figure, rectangular wave pulses are traveling toward each other along a string. The grids shown in the background are identical; the pulses vary in height and length. The pulses will meet and interact soon after they are in the positions shown. Rank the maximum amplitudes $A$ of the string at the instant that the positions of the centers of the two pulses coincide.

a) $A_D > A_C > A_B > A_A$
b) $A_A > A_B > A_C > A_D$
c) $A_C > A_D > A_B > A_A$
d) $A_B > A_C > A_D > A_A$
e) $A_A = A_B = A_C = A_D$
23. A liquid flowing from a vertical pipe has a circular shape as it flows from the pipe. Assume that the liquid is in free fall once it leaves the pipe. Just as it leaves the pipe, the liquid has a speed $v_0$ and the radius of the stream of liquid is $r_0$. What is the speed $v$ of the liquid as a function of the distance $y$ it has fallen?

a) $v = \sqrt{v_0^2 + 2gy}$

b) Have to be given the radius of the stream at the distance $y$ to be able to calculate $v$.

c) $v = \sqrt{2gy}$

d) $v = \sqrt{v_0^2 - 2gy}$

e) $v = v_0 + 2gy$

24. You have $m$ grams of water at $T_1 = 10^\circ$C in a large insulated beaker. How much boiling water with mass $M$ at $T_2 = 100^\circ$C must you add to this beaker so that the final temperature $T_3 = 70^\circ$C?

a) $M = m/2$

b) $M = 10m$

c) $M = 7m$

d) $M = 2m$

e) None of the other answers are correct. Need to know specific heat of water.

25. A monatomic ideal gas has pressure $p_1$ and temperature $T_1$ and is contained in a cylinder of initial volume $V_1$ with a movable piston so that it can do work on the outside world. First, the gas is heated at constant volume until the pressure reaches $p_2 = 2p_1$. The gas then expands at a constant temperature to a volume $V_2 = 2V_1$ when the pressure is back to $p_1$. Finally the gas is cooled at constant pressure back to the initial volume $V_1$. What is the total amount of work $W$ done by the gas?

a) $W = p_1V_1$

b) $W = p_1V_1(2\ln 2 - 1)$

c) $W = p_1V_1(1 - 2\ln 2)$

d) $W = \text{zero}$

e) $W = p_1V_1(2\ln 2)$
26. The diagram shows the pressure and volume of an ideal gas during one cycle of an engine. The pressures and volumes at different stages of the cycle are indicated. What is \( W \), the total work done by the gas during one cycle?

\[
\begin{align*}
\text{a)} \quad W &= 9p_0V_0 \\
\text{b)} \quad W &= 3p_0V_0 \\
\text{c)} \quad W &= 6p_0V_0 \\
\text{d)} \quad W &= 0 \\
\text{e)} \quad W &= 12p_0V_0
\end{align*}
\]

27. Nitrogen gas in an enclosed container of volume \( V \) is initially in a hot bath at temperature \( T_1 \) and pressure \( p_1 \). The container is removed from the hot bath and allowed to cool until the pressure reaches a value of \( p_2 = \frac{p_1}{2} \). What is the temperature \( T_2 \) when the container has reached pressure \( p_2 \)?

\[
\begin{align*}
\text{a)} \quad T_2 &= \frac{T_1}{2} \\
\text{b)} \quad \text{None of the other answers are correct. Need to know } V. \\
\text{c)} \quad T_2 &= T_1 \\
\text{d)} \quad T_2 &= 2T_1 \\
\text{e)} \quad T_2 &= \frac{T_1}{4}
\end{align*}
\]
28. In the figure three identical massless rods are all supported by a fulcrum and are tilted at the same angle to the horizontal. A mass is suspended from the left end of the rod. The rods are held motionless by a downward force on the right end. The locations of the rod with respect to the fulcrum and the values of the suspended masses are shown. Each rod is marked at 1-meter intervals. Rank the magnitude of the vertical force $F$ applied to the end of the rod.

\[ a) \quad F_D > F_E > F_F \]
\[ b) \quad F_F > F_E > F_D \]
\[ c) \quad F_E > F_D > F_F \]
\[ d) \quad F_E = F_F > F_D \]
\[ e) \quad F_D = F_E > F_F \]

29. A simple harmonic oscillator operating at the point $x = 0$ generates a wave on a string. The mathematical form of the wave is

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

If $k = 10 \text{ m}^{-1}$ and $\omega = 40\pi \text{ rad/s}$, what is the value $v$ of the speed of propagation of this wave?

\[ a) \quad v = 4 \text{ m/s} \]
\[ b) \quad v = 40 \text{ m/s} \]
\[ c) \quad v = 4\pi \text{ m/s} \]
\[ d) \quad v = 4/\pi \text{ m/s} \]
\[ e) \quad v = 400 \text{ m/s} \]
30. The figure displays a harmonic oscillator at four different moments in time, labeled A, B, C, and D. The force constant is $k$, the mass of the block is $m$ and the amplitude of vibrations is $A$. At which of these moments of time is the kinetic energy $K$ equal to the potential energy $U$?

a) $K = U$ at moment A.
b) $K = U$ at moments A and C.
c) $K = U$ at moment B.
d) $K = U$ at moment D.
e) $K = U$ at moment C.