# GRE Thermo, Lab Methods, Special Topics

## Equation Sheet, and Sample Problems with Solutions

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# Thermodynamics

Heat Capacity $= C = \Delta Q / \Delta T$   $C = \frac{dU}{dT}$

Specific Heat: $c = \frac{\Delta Q}{m \Delta T}$

$\Delta U = Q - W$   $PV = nRT$   $W = \int P dV$   $dQ = TdS = PdV + dU$

Adiabatic: $\Delta Q = 0$, $\Delta S = 0$   $\Delta U = -W$   $PV^{\gamma} =$ constant   $\gamma = C_p/C_v$

$TV^{\gamma-1} =$ constant

$\gamma = 5/3$ (monatomic, ~~atom~~)   $W_{Ad} = \frac{1}{1-\gamma}(P_2V_2 - P_1V_1)$

IsoTherm: $\Delta U = 0$, $Q = W$   $W = nRT \ln\left(\frac{V_2}{V_1}\right) = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$

$c_v$ (low T) $= \frac{3}{2}Nk = \frac{3}{2}R$   $c_v$ (medium T) $= \frac{5}{2}R$   $c_v$ (high T) $= \frac{7}{2}R$   translation, rotation, vibration

Ideal Gas: $E_{Kinetic} = \frac{3}{2}kT$   $v_{rms} = \sqrt{\frac{3RT}{m}}$   $E_{int} = \frac{3}{2}nRT$   $c_v = \frac{3}{2}R$ (molar specific heat)

Mean Free Path: $\lambda = \frac{1}{\sqrt{2}\pi d^2 \frac{N}{V}}$   d = diameter of molecule

Entropy: $\Delta S = \frac{\Delta Q}{T} = \int_{T_i}^{T_f} \frac{1}{T}\frac{dQ}{dt}dt$   $S = Nk \ln \Omega$

$\Omega = \sum g_i e^{-E_i/kT}$   $g_i$ is degeneracy   Fermi Dirac (2 states): $N_0 \frac{1}{1+e^{-E/kT}}$

Wien law   $W = (\lambda|_{T_{max}})(T_{max})$

Isotherms: Critical lines/points   $\left(\frac{dP}{dV}\Big|_c\right) = \left(\frac{d^2P}{dV^2}\Big|_c\right) = 0$

Efficiency: $\frac{T_1 - T_2}{T_1} = \frac{|W|}{|Q|}$   in KELVIN

Internal energy $= \frac{NkT^2}{\Omega}\frac{d\Omega}{dT}$

#Particles in a state $\propto e^{-E/kT}$ $\quad n_1 = \dfrac{Ne^{-E_1/kT}}{e^{-E_1/kT}+e^{-E_2/kT}+\dots}$ $\quad \sum n_i = N$

Units T in Kelvin ALWAYS Pascal, $m^3$, R = 8.31

(Pascal)($m^3$) = Joule $\quad PV = NkT \quad N$ = # particles

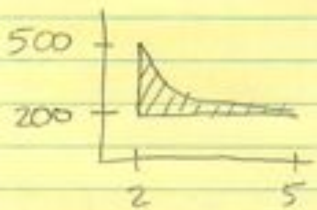
atm, Liter, R = .0821 $\quad 1\,m^3 = 1000L \quad$ 101325 Pa = 1 atm

$\int PdV$ = Work done BY Gas $\quad -\int PdV$ = Work done ON Gas

For a closed PV cycle $T_f = T_i \quad \Delta U = 0 \quad Q = \int PdV$

For counter clockwise $Q<0$, $\Delta S<0$
For clockwise $Q>0$, $\Delta S>0$

Work is area enclosed by the cycle

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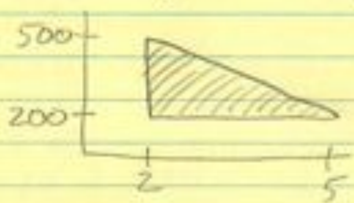
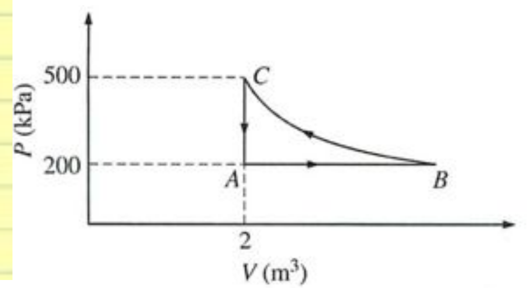



$= \frac{1}{2}(3\,m^3)(300{,}000\ Pa)$

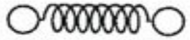
$= 450{,}000\ J$

Counter clockwise $\Rightarrow -450\,kJ < W < 0$




37. A constant amount of an ideal gas undergoes the cyclic process $ABCA$ in the $PV$ diagram shown above. The path $BC$ is isothermal. The work done by the gas during one complete cycle, beginning and ending at $A$, is most nearly

(A) 600 kJ
(B) 300 kJ
(C) 0
(D) −300 kJ
(E) −600 kJ



15. A classical model of a diatomic molecule is a springy dumbbell, as shown above, where the dumbbell is free to rotate about axes perpendicular to the spring. In the limit of high temperature, what is the specific heat per mole at constant volume?

(A) $\frac{3}{2}R$

(B) $\frac{5}{2}R$

(C) $\frac{7}{2}R$

(D) $\frac{9}{2}R$

(E) $\frac{11}{2}R$

62. A mole of ideal gas initially at temperature $T_0$ and volume $V_0$ undergoes a reversible isothermal expansion to volume $V_1$. If the ratio of specific heats is $c_p/c_v = \gamma$ and if $R$ is the gas constant, the work done by the gas is

(A) zero

(B) $RT_0(V_1/V_0)^\gamma$

(C) $RT_0(V_1/V_0 - 1)$

(D) $c_vT_0\left[1 - (V_0/V_1)^{\gamma-1}\right]$

(E) $RT_0 \ln(V_1/V_0)$

63. Which of the following is true if the arrangement of an isolated thermodynamic system is of maximal probability?

(A) Spontaneous change to a lower probability occurs.
(B) The entropy is a minimum.
(C) Boltzmann's constant approaches zero.
(D) No spontaneous change occurs.
(E) The entropy is zero.

A system in thermal equilibrium at temperature $T$ consists of a large number $N_0$ of subsystems, each of which can exist only in two states of energy $E_1$ and $E_2$, where $E_2 - E_1 = \epsilon > 0$. In the expressions that follow, $k$ is the Boltzmann constant.

71. For a system at temperature $T$, the average number of subsystems in the state of energy $E_1$ is given by

(A) $\frac{N_0}{2}$

(B) $\frac{N_0}{1 + e^{-\epsilon/kT}}$

(C) $N_0 e^{-\epsilon/kT}$

(D) $\frac{N_0}{1 + e^{\epsilon/kT}}$

(E) $\frac{N_0 e^{\epsilon/kT}}{2}$

72. The internal energy of this system at any temperature $T$ is given by $E_1N_0 + \frac{N_0\epsilon}{1 + e^{\epsilon/kT}}$. The heat capacity of the system is given by which of the following expressions?

(A) $N_0k\left(\frac{\epsilon}{kT}\right)^2 \frac{e^{\epsilon/kT}}{(1 + e^{\epsilon/kT})^2}$

(B) $N_0k\left(\frac{\epsilon}{kT}\right)^2 \frac{1}{(1 + e^{\epsilon/kT})^2}$

(C) $N_0k\left(\frac{\epsilon}{kT}\right)^2 e^{-\epsilon/kT}$

(D) $\frac{N_0k}{2}\left(\frac{\epsilon}{kT}\right)^2$

(E) $\frac{3}{2}N_0k$

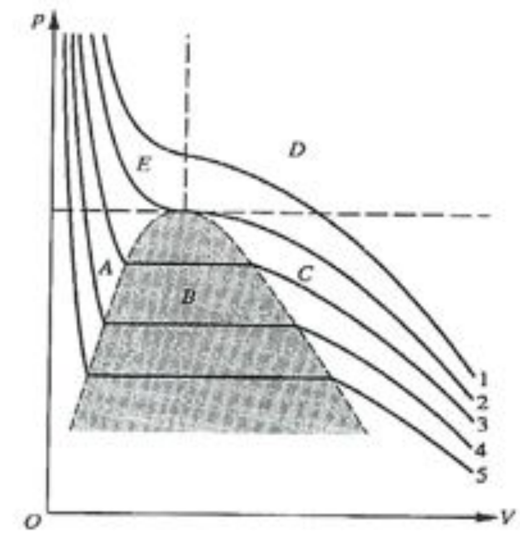
73. Which of the following is true of the entropy of the system?

(A) It increases without limit with $T$ from zero at $T = 0$.
(B) It decreases with increasing $T$.
(C) It increases from zero at $T = 0$ to $N_0k \ln 2$ at arbitrarily high temperatures.
(D) It is given by $N_0k\left[\frac{5}{2}\ln T - \ln p + \text{constant}\right]$.
(E) It cannot be calculated from the information given.

16. An engine absorbs heat at a temperature of 727° C and exhausts heat at a temperature of 527° C. If the engine operates at maximum possible efficiency, for 2000 joules of heat input the amount of work the engine performs is most nearly

(A) 400 J
(B) 1450 J
(C) 1600 J
(D) 2000 J
(E) 2760 J

Questions 46-47




Isotherms and coexistence curves are shown in the $pV$ diagram above for a liquid-gas system. The dashed lines are the boundaries of the labeled regions.

46. Which numbered curve is the critical isotherm?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5

47. In which region are the liquid and the vapor in equilibrium with each other?

(A) A
(B) B
(C) C
(D) D
(E) E

15. Monatomic $c_V = 3/2\, R$ $C_p = C_V + R$ always

Diatomic Normal Temp $C_V = 5/2\, R$ **25%**

62. The key is isothermal ⇒ $W = nRT \ln(V_f / V_i)$

**39%**

63. Maximum Probability ⇒ Equilibrium **46%**

71. # systems in a state is proportional to $e^{-E/kT}$

\# systems with $E_1$ ⇒ $N_0 \dfrac{e^{-E_1/kT}}{e^{-E_1/kT} + e^{-E_2/kT}} = N_0 \dfrac{1}{1 + e^{-\epsilon/kT}}$

\# systems with $E_2$ ⇒ $N_0 \dfrac{e^{-E_2/kT}}{e^{-E_1/kT} + e^{-E_2/kT}} = N_0 \dfrac{1}{e^{\epsilon/kT} + 1}$ **38%**

72. $C = \dfrac{dU}{dT}$ **38%**

73. $S = k \ln \Omega$ $\Omega$ = # of configurations of the system

there are 2 states, so $\Omega = 2^{N_0}$ ⇒ Distinguishable **27%**

16. [1000K] → $Q_{HOT}$ → [Engine] → $Q_{COLD}$ → [800K]

↓ (from Engine)

W

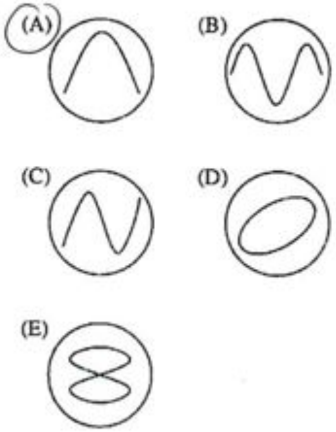
$Q_{HOT} = Q_{COLD} + W$ **44%**

Efficiency $= \dfrac{Q_{HOT} - Q_{COLD}}{Q_{HOT}} = \dfrac{W}{Q_{HOT}} = \dfrac{T_{HOT} - T_{COLD}}{T_{HOT}}$ ⇒ $W = 400\,J$

46. Critical ⇒ There is a point where $\left(\dfrac{dP}{dV}\right) = \dfrac{d^2P}{dV^2} = 0$ **80%**

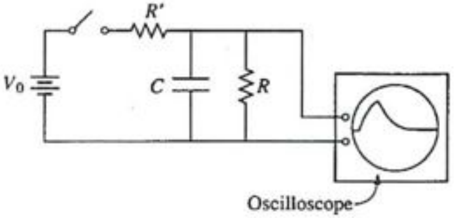
47. **18%**

17. The outputs of two electrical oscillators are compared on an oscilloscope screen. The oscilloscope spot is initially at the center of the screen. Oscillator $Y$ is connected to the vertical terminals of the oscilloscope and oscillator $X$ to the horizontal terminals. Which of the following patterns could appear on the oscilloscope screen, if the frequency of oscillator $Y$ is twice that of oscillator $X$?




91. The particle decay $\Lambda \rightarrow p + \pi^-$ must be a weak interaction because

(A) the $\pi^-$ is a lepton
(B) the $\Lambda$ has spin zero
(C) no neutrino is produced in the decay
(D) it does not conserve angular momentum
(E) it does not conserve strangeness




86. The circuit shown above is used to measure the size of the capacitance $C$. The $y$-coordinate of the spot on the oscilloscope screen is proportional to the potential difference across $R$, and the $x$-coordinate of the spot is swept at a constant speed $s$. The switch is closed and then opened. One can then calculate $C$ from the shape and the size of the curve on the screen plus a knowledge of which of the following?

(A) $V_0$ and $R$
(B) $s$ and $R$
(C) $s$ and $V_0$
(D) $R$ and $R'$
(E) The sensitivity of the oscilloscope

48. The magnitude of the force $F$ on an object can be determined by measuring both the mass $m$ of an object and the magnitude of its acceleration $a$, where $F = ma$. Assume that these measurements are uncorrelated and normally distributed. If the standard deviations of the measurements of the mass and the acceleration are $\sigma_m$ and $\sigma_a$, respectively, then $\sigma_F/F$ is

(A) $\left(\frac{\sigma_m}{m}\right)^2 + \left(\frac{\sigma_a}{a}\right)^2$

(B) $\left(\frac{\sigma_m}{m} + \frac{\sigma_a}{a}\right)^{\frac{1}{2}}$

(C) $\left[\left(\frac{\sigma_m}{m}\right)^2 + \left(\frac{\sigma_a}{a}\right)^2\right]^{\frac{1}{2}}$

(D) $\frac{\sigma_m \sigma_a}{ma}$

(E) $\frac{\sigma_m}{m} + \frac{\sigma_a}{a}$

49. Two horizontal scintillation counters are located near the Earth's surface. One is 3.0 meters directly above the other. Of the following, which is the largest scintillator resolving time that can be used to distinguish downward-going relativistic muons from upward-going relativistic muons using the relative time of the scintillator signals?

(A) 1 picosecond
(B) 1 nanosecond
(C) 1 microsecond
(D) 1 millisecond
(E) 1 second

97. Lattice forces affect the motion of electrons in a metallic crystal, so that the relationship between the energy $E$ and wave number $k$ is not the classical equation $E = \hbar^2k^2/2m$, where $m$ is the electron mass. Instead, it is possible to use an effective mass $m^*$ given by which of the following?

(A) $m^* = \frac{1}{2}\hbar^2 k \left(\frac{dk}{dE}\right)$

(B) $m^* = \frac{\hbar^2 k}{\left(\frac{dk}{dE}\right)}$

(C) $m^* = \hbar^2 k \left(\frac{d^2k}{dE^2}\right)^{\frac{1}{3}}$

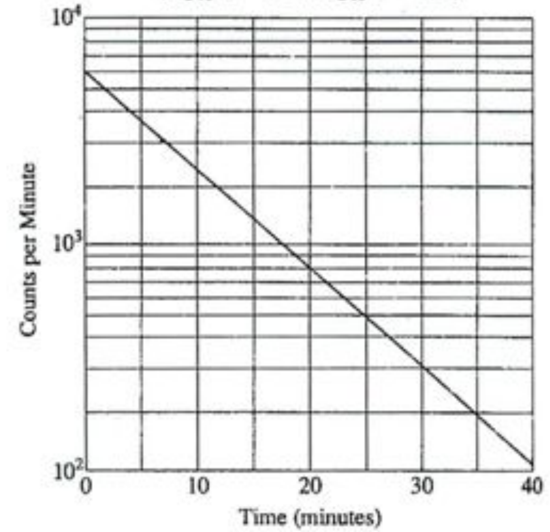
(D) $m^* = \frac{\hbar^2}{\left(\frac{d^2E}{dk^2}\right)}$

(E) $m^* = \frac{1}{2}\hbar^2 m^2 \left(\frac{d^2E}{dk^2}\right)$

25. In experiments located deep underground, the two types of cosmic rays that most commonly reach the experimental apparatus are

(A) alpha particles and neutrons
(B) protons and electrons
(C) iron nuclei and carbon nuclei
(D) muons and neutrinos
(E) positrons and electrons

($\log_{10} 2 = 0.30$; $\log_{10} e = 0.43$)




26. A radioactive nucleus decays, with the activity shown in the graph above. The half-life of the nucleus is

(A) 2 min
(B) 7 min
(C) 11 min
(D) 18 min
(E) 23 min

18. In transmitting high frequency signals on a coaxial cable, it is important that the cable be terminated at an end with its characteristic impedance in order to avoid

(A) leakage of the signal out of the cable
(B) overheating of the cable
(C) reflection of signals from the terminated end of the cable
(D) attenuation of the signal propagating in the cable
(E) production of image currents in the outer conductor

17. B $\omega_y = 3\omega_x$  C $\omega_y = 3\omega_x$  D $\omega_y = \omega_x$  E $\omega_y = \frac{1}{2}\omega_x$  **10%**

91. Fact **23%**

86. We are seeing charging and discharging a capacitor for an RC circuit. $V(t) = V_0 e^{-t/RC}$ when the potential is falling. We can determine RC if we know s, we can say $\Delta x = s\Delta t$ => find RC  **41%**

48. Uncorrelated uncertainties $f(x,y,z)$  $\sigma_f^2 = \sigma_x^2\left(\frac{\partial f}{\partial x}\right)^2 + \sigma_y^2\left(\frac{\partial f}{\partial y}\right)^2 + \sigma_z^2\left(\frac{\partial f}{\partial z}\right)^2$  $F = ma$  $\sigma_F^2 = \sigma_m^2\left(\frac{\partial F}{\partial m}\right)^2 + \sigma_a^2\left(\frac{\partial F}{\partial a}\right)^2 = \sigma_m^2 a^2 + \sigma_a^2 m^2$  **66%**

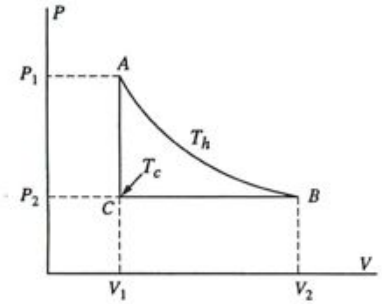
49. Fast muon $v \sim c$  3 meters => $10^{-8}$ sec. We need to know the muon hit the lower detector $10^{-8} = 10$ nano seconds after the top detector.  **48%**

97. $E = \hbar^2 k^2/2m$  $\frac{dE}{dk} = \frac{\hbar^2 k}{m}$  $\frac{d^2E}{dk^2} = \frac{\hbar^2}{m}$  $m = \hbar^2 k / \left(\frac{dE}{dk}\right) = \hbar^2 / \left(\frac{d^2E}{dk^2}\right)$  **9%**

25. Fact **84%**

26. $t = 0$  6000 counts  $t \approx 7$ min  3000 counts  **57%**

18. Fact **69%**




15. Suppose one mole of an ideal gas undergoes the reversible cycle $ABCA$ shown in the $P$-$V$ diagram above, where $AB$ is an isotherm. The molar heat capacities are $C_p$ at constant pressure and $C_v$ at constant volume. The net heat added to the gas during the cycle is equal to

(A) $RT_hV_2/V_1$
(B) $-C_p(T_h - T_c)$
(C) $C_v(T_h - T_c)$
(D) $RT_h \ln V_2/V_1 - C_p(T_h - T_c)$
(E) $RT_h \ln V_2/V_1 - R(T_h - T_c)$

16. The mean free path for the molecules of a gas is approximately given by $\frac{1}{\eta\sigma}$, where $\eta$ is the number density and $\sigma$ is the collision cross section. The mean free path for air molecules at room conditions is approximately

(A) $10^{-4}$ m
(B) $10^{-7}$ m
(C) $10^{-10}$ m
(D) $10^{-13}$ m
(E) $10^{-16}$ m

74. A body of mass $m$ with specific heat $C$ at temperature 500 K is brought into contact with an identical body at temperature 100 K, and the two are isolated from their surroundings. The change in entropy of the system is equal to

(A) $(4/3)mC$
(B) $mC\ln(9/5)$
(C) $mC\ln(3)$
(D) $-mC\ln(5/3)$
(E) 0

79. For an ideal diatomic gas in thermal equilibrium, the ratio of the molar heat capacity at constant volume at very high temperatures to that at very low temperatures is equal to

(A) 1
(B) 5/3
(C) 2
(D) 7/3
(E) 3

73. The adiabatic expansion of an ideal gas is described by the equation $PV^\gamma = C$, where $\gamma$ and $C$ are constants. The work done by the gas in expanding adiabatically from the state $(V_i, P_i)$ to $(V_f, P_f)$ is equal to

(A) $P_fV_f$
(B) $\frac{(P_i + P_f)}{2}(V_f - V_i)$
(C) $\frac{P_fV_f - P_iV_i}{1-\gamma}$
(D) $\frac{P_i(V_f^{1+\gamma} - V_i^{1+\gamma})}{1+\gamma}$
(E) $\frac{P_f(V_f^{1-\gamma} - V_i^{1-\gamma})}{1+\gamma}$

13. A 100-watt electric heating element is placed in a pan containing one liter of water. Although the heating element is on for a long time, the water, though close to boiling, does not boil. When the heating element is removed, approximately how long will it take the water to cool by 1° C ? (Assume that the specific heat for water is 4.2 kilojoules/kilogram °C.)

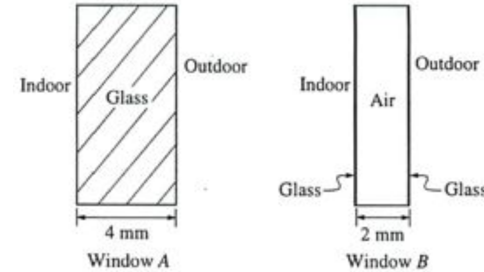
(A) 20 s
(B) 40 s
(C) 60 s
(D) 130 s
(E) 200 s

14. Two identical 1.0-kilogram blocks of copper metal, one initially at a temperature $T_1 = 0°$ C and the other initially at a temperature $T_2 = 100°$ C, are enclosed in a perfectly insulating container. The two blocks are initially separated. When the blocks are placed in contact, they come to equilibrium at a final temperature $T_f$. The amount of heat exchanged between the two blocks in this process is equal to which of the following? (The specific heat of copper metal is equal to 0.1 kilocalorie/kilogram °K.)

(A) 50 kcal
(B) 25 kcal
(C) 10 kcal
(D) 5 kcal
(E) 1 kcal

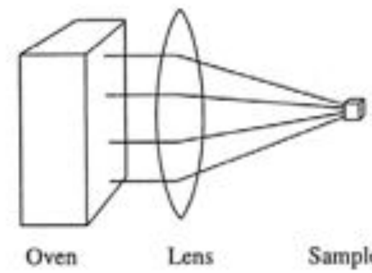
**94. A system consists of $N$ weakly interacting subsystems, each with two internal quantum states with energies 0 and $\epsilon$. The internal energy for this system at absolute temperature $T$ is equal to**

(A) $N\epsilon$
(B) $\frac{3}{2}NkT$
(C) $N\epsilon e^{-\epsilon/kT}$
(D) $\frac{N\epsilon}{(e^{\epsilon/kT} + 1)}$
(E) $\frac{N\epsilon}{(1 + e^{-\epsilon/kT})}$




75. Window $A$ is a pane of glass 4 millimeters thick, as shown above. Window $B$ is a sandwich consisting of two extremely thin layers of glass separated by an air gap 2 millimeters thick, as shown above. If the thermal conductivities of glass and air are 0.8 watt/meter °C and 0.025 watt/meter °C, respectively, then the ratio of the heat flow through window $A$ to the heat flow through window $B$ is

(A) 2
(B) 4
(C) 8
(D) 16
(E) 32




91. An experimenter needs to heat a small sample to 900 K, but the only available oven has a maximum temperature of 600 K. Could the experimenter heat the sample to 900 K by using a large lens to concentrate the radiation from the oven onto the sample, as shown above?

(A) Yes, if the volume of the oven is at least 3/2 the volume of the sample.
(B) Yes, if the area of the front of the oven is at least 3/2 the area of the front of the sample.
(C) Yes, if the sample is placed at the focal point of the lens.
(D) No, because it would violate conservation of energy.
(E) No, because it would violate the second law of thermodynamics.

15. $W_{tot} = Q_{tot}$ $\quad W = 0 + RT_H \ln(V_2/V_1) + P_2(V_1 - V_2)$

$= RT_H \ln(V_2/V_1) + R(T_c - T_H)$ or $RT_H \ln(V_2/V_1) + (T_H - T_c)(C_V - C_p)$

If we add $Q_{A\to B} + Q_{B\to C} + Q_{C\to A}$ [12%] → Too long

16. $PV = nRT = NkT$ $\quad \eta = \frac{N}{V} = \frac{P}{kT} = \frac{101325}{300k} \sim \frac{10^5}{4\times10^{-21}} \sim 2\times10^{25}$

Atomic diameter $\sim 10^{-10}$ $\quad \sigma \sim \pi r^2 = \pi\times10^{-20}$ $\quad \frac{1}{\eta\sigma} \sim \frac{1}{2\pi\times10^5}$ $\quad 10^{-7}$ [20%]

74. $\Delta S_1 + \Delta S_2 = mC\ln(300/500) + mC\ln\left(\frac{300}{100}\right) = mC\ln(9/5)$ [21%]

73. Must have dimension PV, not D, E. Not A, B is for $P = \alpha V + \beta$ linear relationship ⇒ Not adiabatic [34%]

79. Fast [22%]

94. # of particles in a state is proportional to $e^{-E/kT}$ [28%]

$E_{tot} = N\frac{1}{1+e^{-\epsilon/kT}}(0) + N\frac{e^{-\epsilon/kT}}{1+e^{-\epsilon/kT}}(\epsilon) = N\epsilon\frac{1}{1+e^{\epsilon/kT}}$

13. 100 W in and 100W out because no boiling [37%]

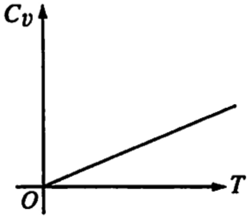
$1L \Rightarrow 1kg$ $\quad \Delta Q = 4200(\Delta T)m = 4200 = 100(\Delta t)$ $\quad \Delta t = 42$ sec

14. $T_f = 50°C$ $\quad \Delta Q = (1kg)(.1)(50) = 5$ kcal [66%]

75. $\Delta Q = \sigma\frac{\Delta T}{\Delta x}$ $\quad \frac{\Delta Q_A}{\Delta Q_B} = \frac{\sigma_A x_B}{\sigma_B x_A} = \frac{.8}{.025}\frac{1}{2} = \frac{.8}{.05} = 16$ [27%]

91. [25%]

95. Which of the following curves is characteristic of the specific heat $C_V$ of a metal such as lead, tin, or aluminum in the temperature region where it becomes superconducting?

(A)
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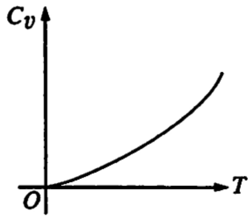


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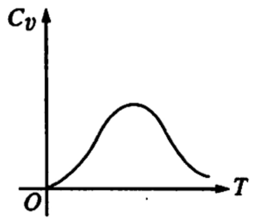
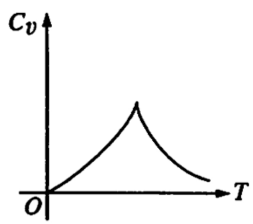
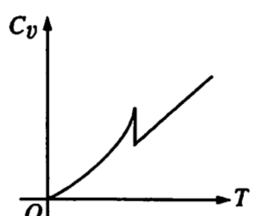



(D)



(E)



27. In laboratory experiments, graphs are employed to determine how one measured variable depends on another. These graphs generally fall into three categories: linear, semilog (logarithmic *versus* linear), and log-log. Which type of graph listed in the third column below would NOT be the best for plotting data to test the relationship given in the first and second columns?

| Relation | Variables Plotted | Type of Graph |
|---|---|---|
| (A) $dN/dt \propto e^{-2t}$ | Activity *vs.* time for a radioactive isotope | Semilog |
| (B) $eV_s = hf - W$ | Stopping potential *vs.* frequency for the photoelectric effect | Linear |
| (C) $s \propto t^2$ | Distance *vs.* time for an object undergoing constant acceleration | Log-log |
| (D) $V_{out}/V_{in} \propto 1/\omega$ | Gain *vs.* frequency for a low-pass filter | Linear |
| (E) $P \propto T^4$ | Power radiated *vs.* temperature for blackbody radiation | Log-log |

LOG LOG

78. In an *n*-type semiconductor, which of the following is true of impurity atoms?

(A) They accept electrons from the filled valence band into empty energy levels just above the valence band.
(B) They accept electrons from the filled valence band into empty energy levels just below the valence band.
(C) They accept electrons from the conduction band into empty energy levels just below the conduction band.
(D) They donate electrons to the filled valence band from donor levels just above the valence band.
(E) They donate electrons to the conduction band from filled donor levels just below the conduction band.

10. Internal conversion is the process whereby an excited nucleus transfers its energy directly to one of the most tightly bound atomic electrons, causing the electron to be ejected from the atom and leaving the atom in an excited state. The most probable process after an internal conversion electron is ejected from an atom with a high atomic number is that the

(A) atom returns to its ground state through inelastic collisions with other atoms
(B) atom emits one or several x-rays
(C) nucleus emits a $\gamma$-ray
(D) nucleus emits an electron
(E) nucleus emits a positron

72. In a voltage amplifier, which of the following is NOT usually a result of introducing negative feedback?

(A) Increased amplification
(B) Increased bandwidth
(C) Increased stability
(D) Decreased distortion
(E) Decreased voltage gain

34. When the beta-decay of $^{60}$Co nuclei is observed at low temperatures in a magnetic field that aligns the spins of the nuclei, it is found that the electrons are emitted preferentially in a direction opposite to the $^{60}$Co spin direction. Which of the following invariances is violated by this decay?

(A) Gauge invariance
(B) Time invariance
(C) Translation invariance
(D) Reflection invariance
(E) Rotation invariance

63. According to the Standard Model of elementary particles, which of the following is NOT a composite object?

(A) Muon
(B) Pi-meson
(C) Neutron
(D) Deuteron
(E) Alpha particle

Fin