1. Which of the following situations is described by the zeroth law of thermodynamics?
   
   A. A physicist removes energy from a system until it reaches a temperature of 0.3 nK, close to but still greater than absolute zero.
   
   B. A gas is in a container with a piston. The gas absorbs heat from the surroundings and expands at constant pressure.
   
   C. A container with insulating walls holds boiling water. A thermometer is calibrated by inserting it and allowing it to reach thermal equilibrium with the water.
   
   D. A pot contains oil at 175°C. When frozen sliced potatoes are dropped into the oil, heat is transferred from the oil to the potatoes.

2. Which of the following properties is not suitable to be used as the basis of a thermometer?
   
   A. The volume of a liquid increases with increasing temperature.
   
   B. A gas in a constant-volume container exhibits pressure changes that depend on temperature.
   
   C. The length of a metal rod changes linearly with temperature.
   
   D. The mass of a solid decreases with increasing temperature.
   
   E. The electrical resistance of a wire increases with increasing temperature.

3. You create your own temperature scale. On your scale, the ice point is 0.0°M and the steam point is at 366.1°M, where “M” stands for “my scale.” What temperature on your scale is absolute zero?
   
   A. -273.1°M
   
   B. -500.0°M
   
   C. -1000.0°M
   
   D. -732.4°M
   
   E. -633.9°M

4. Is there a temperature which has the same numerical value in °F and °C?
   
   A. No, because a change by 1.0°C equals a change by 1.8°F.
   
   B. No, because it would occur at a temperature below absolute zero.
   
   C. Yes, at -40.
   
   D. Yes, at the boiling point of liquid sulfur.

5. An artist wishes to insert a gold pin into a hole in a gold sculpture. The pin is slightly larger than the hole. Which of the following could accomplish the task?
   
   A. increase the temperature of the pin and the sculpture by the same amount
   
   B. decrease the temperature of the pin and the sculpture by the same amount
   
   C. decrease the temperature of the sculpture only
   
   D. increase the temperature of the sculpture only
6. An aluminum physical pendulum in a clock keeps accurate time when the temperature is 23.3°C. The clock is hung on a wall where the temperature is 11.5°C. What happens?
   A. the clock loses time
   B. the clock continues to keep accurate time
   C. the clock gains time

7. Two rods of the same material are heated in an oven to 300°C. Rod A is 30 cm long and rod B is 20 cm long. What is the ratio of the change in length of rod A to B?
   A. 1/3
   B. 2/3
   C. 1
   D. 3/2
   E. 3

8. Why do metal pipes that carry water often burst during cold winter months?
   A. Both the metal and the water contract, but the metal contracts more.
   B. The interior diameter of the pipe fractionally contracts more than the outer diameter of the pipe.
   C. Water expands upon freezing, while the metal contracts.

9. Four blocks made from the same material are shown. The sides have lengths L, 2L, or 3L. Rank the blocks according to their increase in volume, largest to smallest, when their temperatures are raised the same amount.

   A. B > C > A > D
   B. C > B > A > D
   C. D > C > A > B
   D. C > D > B > A

10. A square piece of metal has a hole drilled in its center. If the metal piece is uniformly heated, what happens?
    A. The diameter of the hole will decrease.
    B. The diameter of the hole will increase.
    C. The diameter of the hole will not change, but the area of the square plate will increase.
11 Why is water often used as a coolant in car radiators, other than the fact that it is abundant?

A Water expands very little as it is heated.
B The freezing temperature of water is relatively high.
C The specific heat of water is relatively large.
D Water is not easily vaporized.

12 The same amount of heat is added to materials A, B, and C of masses 0.04, 0.01, and 0.02 kg, respectively. The temperature of material A increases by 4.0°C while that of the other two materials increases by only 3.0°C. Rank the materials from largest to smallest heat capacity.

A A > B > C
B C > B > A
C B > A > C
D B = C > A
E A > B = C

13 A swimming pool has a width of 9 m, a length of 11 m, and a depth of 2 m. One morning, the temperature of the pool water was 15.0°C. The water then absorbed 2 GJ of heat from the Sun. What is the final temperature of the water, ignoring heat losses?

A 16.9°C
B 18.1°C
C 17.4°C
D 19.6°C
E 20.2°C

14 Which of the following would be the most effective in cooling 300 g of water at 98°C if added to it?

A 100 g of lead at 22°C
B 100 g of water at 22°C
C 100 g of window glass at 22°C

15 Four 1-kg cylinders are heated to 100°C and placed on a block of wax which melts at 63°C. One cylinder is lead, one is copper, one is aluminum, and one is iron. After a few minutes, the cylinders have sunk into the wax to depths from deepest to shallowest of:

A lead > iron > copper > aluminum
B aluminum > copper > lead > iron
C aluminum > iron > copper > lead
D copper > aluminum > iron > lead
E iron > copper > lead > aluminum
16 What is the final temperature when 250 kJ are added to 950 g of ice at 0.0°C?
   A  0.0°C
   B  4.2°C
   C  15.7°C
   D  36.3°C
   E  62.8°C

17 By adding 25 kJ to solid A, 4.0 kg will melt. By adding 50 kJ to solid B, 6.0 kg will melt. Solid C requires 30 kJ to melt 3.0 kg. Which has the largest heat of fusion?
   A  A
   B  B
   C  C

18 A test tube of room temperature water is inserted into a large amount of initially boiling water in a vacuum flask. Will the water in the test tube eventually boil?
   A  Yes because heat is continuously transferred to the water in the test tube.
   B  No, heat will only be transferred until the water in the test tube is 100°C but it won't boil.
   C  No because the temperature of the water in the test tube will not reach 100°C.

19 An insulated container is filled with a mixture of water and ice. An electric coil adds 1680 J of heat to it while a mixer does 450 J of work on it by stirring. What is the increase in the internal energy of the ice water?
   A  450 J
   B  1230 J
   C  1680 J
   D  2130 J
   E  zero

20 The internal energy of a system increases during some time interval. What is the sign of the net heat added to the system during that time?
   A  positive
   B  negative
   C  it could have either sign
21 A gas is in an uninsulated cylinder with a piston. The volume of the gas is halved by applying a force to the piston. What is the sign of the change in internal energy of the gas?

A positive
B negative
C it could have either sign

22 A gas is in an uninsulated cylinder with a piston. The volume of the gas is halved by applying a force to the piston. What is the sign of the work done on the gas?

A positive
B negative
C it could have either sign

23 For which process does the work done have the largest absolute value?

\[
\begin{array}{c}
\text{A}\ G-H-B-D \\
\text{B}\ G-F-B-D \\
\text{C}\ H-A-B-D \\
\text{D}\ E-D-F-H \\
\text{E}\ C-B-F-G
\end{array}
\]

24 If the initial state of the system is at A and the final state is at E, which of these paths results in the largest increase in internal energy of the system?

\[
\begin{array}{c}
\text{A}\ A-H-D-E \\
\text{B}\ A-B-F-E \\
\text{C}\ A-B-C-D-E \\
\text{D}\ A-H-G-F-E \\
\text{E}\ all\ give\ equal\ increase
\end{array}
\]
25 An insulated container with rigid walls has two compartments. One compartment contains an ideal gas and the other is evacuated. A valve connecting the two chambers is opened. What happens as the gas equilibrates between the two chambers?

A There is no change in the internal energy of the gas.
B There is no change in the pressure of the gas.
C The temperature of the gas decreases.
D Work is done by the gas.

26 Sunlight warms the land beside a cool lake. As a result, a breeze blows from the lake toward the land. Why?

A Air is driven in the direction of the flowing heat.
B Water vapor above the lake expands and pushes air toward the land.
C Warm air rises above the land and is replaced by air blowing in from the lake.

27 Thermometers at different depths and radii in a pot of water on a stove all read about the same as it warms up from room temperature to boiling. Which form of heat transfer explains the uniform temperature throughout the pot:

A convection within the water
B conduction from the bottom and sides of the pot to the water
C radiation from the heating element to the pot

28 A candle is burning at the bottom of a tube with a second tube just above the candle as shown. What will happen if the second tube is removed?

A The flame will go out.
B It will burn less brightly.
C It won't change.
D The flame will burn brighter.

29 Cylinders at room temperature are held in your hand. Which one feels the coolest?

A aluminum
B copper
C steel
D wood
E They all feel the same.
30 A wall is composed of four different materials. Rank them in order of decreasing thermal conductivity.

A: A > C > B > D
B: B > C > D > A
C: C > B > D > A
D: D > A > C > B
E: A > D > B > C

31 The thermal conductivity of bar A is three times that of B. The cross-sectional area of bar A is half that of B. Which is correct?

A: The heat flow in A is 3 times that in B.
B: The heat flow in A is 3/2 times that in B.
C: The heat flow in A is the same as that in B.
D: The heat flow in A is 2/3 times that in B.
E: The heat flow in A is 1/3 times that in B.

32 What thickness of concrete with a thermal conductivity of 1.1 W/m K will conduct heat at the same rate as 0.25 m of air which has a thermal conductivity of 0.025 W/m K, if all other conditions are the same?

A: 0.025 m
B: 0.11 m
C: 0.25 m
D: 11 m
Just before spring, a plane flies over the mountains and drops black soot on the snow and ice. How does this procedure help prevent flooding of the valley below when warmer weather arrives?

A  It increases the absorption of sunlight, so melting occurs earlier and more gradually.
B  It increases the temperature at which the snow and ice melt, so less melting occurs.
C  It has a higher thermal conductivity than snow and ice, and so transmits heat from the air more efficiently.
D  It insulates the snow and ice, and so the reduced convection decreases the melting.

Thermos flasks are usually shiny inside to reduce heat losses via:

A  conduction
B  convection
C  radiation

A device is for use in the desert. The front side facing the sun should absorb little heat, while the shaded back side should lose little heat. Two materials for these sides are considered: (1) a dull black material and (2) a shiny metallic material. Which should be used?

A  The front should be 2 and the back should be 1.
B  The front should be 1 and the back should be 2.
C  Both sides should be 1.
D  Both sides should be 2.
E  It doesn't matter for either side.

Two sealed containers are initially at the same temperature and have the same dimensions. The outer surfaces of container A are polished shiny aluminum. That of B are roughened grey iron. An incandescent lamp shines on each for equal times from equal distance. Within which container will the temperature increase the quickest?

A  A
B  B
C  both equal

Using the density of water and Avogadro’s number, estimate the size of a water molecule by assuming each molecule fits within a cube and that these cubes are stacked to fill the volume of a container.

A  0.4 Angstroms
B  3 Angstroms
C  6 Angstroms
D  20 Angstroms
38 A real gas behaves like an ideal gas if:
   A  The gas particles move slowly.
   B  The interaction between particles is negligible.
   C  The gas particles seldom collide with the walls.

39 If the final temperature of an ideal gas is double the initial temperature and the volume is a quarter the initial value, what will be the final pressure of the gas compared to its initial pressure?
   A  8 times bigger
   B  4 times bigger
   C  2 times bigger
   D  1/2 as big
   E  1/4 as big
   F  1/8 as big

40 Two sealed containers are at the same temperature and each contain the same number of moles of the same ideal gas. Which is true?
   A  The rms speed of the atoms is greater in B than in A.
   B  The collision frequency of atoms with the walls in B is greater than that in A.
   C  The total kinetic energy of the gas is greater in B than in A.
   D  The average force that an atom exerts on the walls of B is greater than in A.

41 Two containers at room temperature have the same volume and are filled with the same number of moles of gas. But one is filled with helium and the other with neon. Which is true?
   A  The average kinetic energy of the neon atoms is greater than that of the helium atoms.
   B  The pressure in the helium container is less than in the neon container.
   C  The rms speed of the neon atoms is less than that of the helium atoms.

42 A monatomic gas is in a container of constant volume. By what factor does the rms speed change when the gas temperature is tripled?
   A  3
   B  square root of 3
   C  9
At sea level, the mean free path of air molecules is 60 nm. At an altitude of 100 km, the mean free path is 10 cm. Which of the following best explains this difference?

A. The molecules in the atmosphere have smaller average diameters at high altitudes than at sea level.
B. Air temperature is lower at high altitudes than at sea level.
C. Air density is smaller at high altitudes than at sea level.

Which setup guarantees an isobaric process?

A. A gas cylinder is immersed in an ice-water bath held at constant temperature
B. A gas cylinder is capped on top by a heavy moveable piston.
C. A gas cylinder is enclosed in a container having constant volume.
D. A gas cylinder is connected to a source that maintains a constant molecular number density.

How can you ensure an ideal gas undergoes an adiabatic process?

A. Keep it in contact with an ice-water bath held at constant temperature.
B. Keep its pressure constant using a regulator.
C. Enclose it in a rigid container so it has constant volume.
D. Push down on a piston rapidly compared to the speed of thermal transfer to the surroundings.

An ideal gas is separated from a vacuum space by an elastic sheet. The sheet is punctured so that the gas makes a free expansion. Why can't we plot the intermediate points on the trajectory of a pressure-volume graph for the gas?

A. The gas is not in equilibrium.
B. The gas is not enclosed in a single volume.
C. The gas temperature is changing rapidly.

An ideal monatomic gas is compressed adiabatically and quasi-statically. When the volume decreases to one-eighth of its initial value, by how much has the pressure increased?

A. 2 times
B. 4 times
C. 8 times
D. 16 times
E. 32 times
48 An ideal gas is compressed adiabatically & quasi-statically. What are the signs of (1) the heat transferred TO the environment, (2) the work done ON the environment, and (3) the change in internal energy OF the gas?

A (1) is zero, (2) is negative, and (3) is negative
B (1) is negative, (2) is positive, and (3) is negative
C (1) is zero, (2) is negative, and (3) is positive
D (1) is zero, (2) is positive, and (3) is negative
E (1) is positive, (2) is negative, and (3) is zero

49 An ideal gas has initial temperature $T_0$ and pressure $P_0$. The gas undergoes a reversible isothermal compression from initial volume $V_0$ to final volume $0.5V_0$. How much heat is exchanged with the environment?

A Heat $0.5P_0V_0$ is released to the environment.
B Heat $0.5P_0V_0$ is absorbed from the environment.
C No heat is exchanged with the environment.
D Heat $P_0V_0 \ln 2$ is released to the environment.
E Heat $P_0V_0 \ln 2$ is absorbed from the environment.

50 An ideal gas may be taken along one of two paths from state A to B. Path 1 runs vertically upward. Path 2 follows route A-C-B. How does the amount of work done by the gas compare along each path?

A $W_1 = W_2$ and both are nonzero
B $W_1 = W_2 = 0$
C $W_1 > W_2$
D $W_1 < W_2$

51 A car engine has an efficiency of 25%. While being driven on a trip, 12 gallons of gasoline are consumed. How much of that gas was used in doing work to propel the car?

A about 12 gallons
B about 8 gallons
C about 3 gallons
D about 1 gallon
52 You are repairing a refrigerator with its door off in a closed workroom with no heating or cooling. You succeed in getting it to work, but are called away after you turn it on. How does the temperature of the workroom change in your absence?

A it gets colder  
B it stays the same temperature  
C it gets warmer

53 An air conditioner pumps heat from a cold room to the hot outdoors. Why doesn't that violate the second law of thermodynamics?

A The internal energy of the gas is constant over a complete cycle.  
B Electrical work is continuously done on the system.  
C The compressor adds entropy to the process.

54 You make ice in a freezer. Why doesn't that violate the second law of thermodynamics?

A When the ice is later melted, the entropy will increase back to what it was before it was frozen.  
B The entropy of the universe increases when we include the operating cycle of the freezer.  
C The entropy of the water initially decreases but later increases during the freezing process.  
D The entropy of the freezer compartment overall increases to offset the decrease in the entropy of the icemaking.

55 Consider the dice shown as a thermodynamic system. What corresponds to the microstates and macrostates?

![Dice Image]

A The number on a die (e.g. 6) corresponds to a microstate; the set of numbers on all the dice (1, 2, 4, 6) corresponds to a macrostate.  
B The number on a die (e.g. 6) corresponds to a microstate; the sum of the numbers on all the dice (13) corresponds to a macrostate.  
C The set of numbers on all the dice (1, 2, 4, 6) corresponds to a microstate; the sum of the numbers on all the dice (13) corresponds to a macrostate.
Consider the dice shown as a thermodynamic system. Which of the following microstates is least likely to occur?

A  \{1, 1, 1, 1\}
B  \{1, 1, 6, 6\}
C  \{1, 2, 4, 6\}
D  All microstates are equally likely.

Consider the dice shown as a thermodynamic system. The sum of the numbers on the dice corresponds to the macrostate. Which one of the following macrostates is least likely to occur?

A  4
B  8
C  10
D  16
E  All macrostates are equally likely.

R is the inner workings of a refrigerator unit, Q1 and Q2 are heat that is being transferred, W is an amount of work, and L is leftovers in the cold compartment. What are the correct directions for arrows 1 and 2?

A  1 points to R, and 2 points to L.
B  1 points away from R, and 2 points to R.
C  1 points to R, and 2 points to R.
D  1 points away from R, and 2 points to L.
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