SAT Subject Physics Key Formulas

Conversion between Fahrenheit and Celsius	$y^\circ\mathrm{F} = \frac{9}{5}x^\circ\mathrm{C} + 32$
Conversion between Celsius and Kelvin	$0^\circ\mathrm{C} = 273\,\mathrm{K}$ $\mathrm{K} = {}^\circ\mathrm{C} + 273$
Relationship between Heat and Temperature	$Q = mc\Delta T$
Coefficient of Linear Expansion	$\Delta L = \alpha L_i \Delta T$
Coefficient of Volume Expansion	$\Delta V = \beta V_i \Delta T$
Ideal Gas Law	$PV = nRT$
Boyle’ s Law	$P_i V_i = P_f V_f$
Charles’ s Law	$\frac{V_i}{T_i} = \frac{V_f}{T_f}$
First Law of Thermodynamics	$\Delta U = \Delta Q + \Delta W$
Efficiency of a Heat Engine	$e = 1 - \frac{\Delta Q_{\mathrm{out}}}{\Delta Q_{\mathrm{in}}}$
Theoretical Limits on Heat Engine Efficiency	$0 \le e < 1$

Practice Questions

1. 1 kg of cold water at 5Â°C is added to a container of 5 kg of hot water at 65Â° C. Wh the final temperature of the water when it arrives at thermal equilibrium?

   (A) 10Â°C

   (B) 15Â°C

   (C) 35Â°C

   (D) 55Â°C

   (E) 60Â°C

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2. Which of the following properties must be known in order to calculate the amount of heat r to melt 1.0 kg of ice at 0Âº C?

I. The specific heat of water

II. The latent heat of fusion for water

III. The density of water

(A) I only

(B) I and II only

(C) I, II, and III

(D) II only

(E) I and III only

3. Engineers design city sidewalks using blocks of asphalt separated by a small gap to pr them from cracking. Which of the following laws best explains this practice?

(A) The Zeroth Law of Thermodynamics

(B) The First Law of Thermodynamics

(C) The Second Law of Thermodynamics

(D) The law of thermal expansion

(E) Conservation of charge

4. Which of the following is an example of convection?

(A) The heat of the sun warming our planet

(B) The heat from an electric stove warming a frying pan

(C) Ice cubes cooling a drink

(D) A microwave oven cooking a meal

(E) An overhead fan cooling a room

5. An ideal gas is enclosed in a sealed container. Upon heating, which property of the gas not change?

(A) Volume

(B) Pressure

(C) The average speed of the molecules

(D) The rate of collisions of the molecules with each other

(E) The rate of collisions of the molecules with the walls of the container

6. A box contains two compartments of equal volume separated by a divider. The two compart each contain a random sample of n moles of a certain gas, but the pressure in compartr is twice the pressure in compartment B. Which of the following statements is true?

(A) The temperature in A is twice the temperature in B

(B) The temperature in B is twice the temperature in A

(C) The value of the ideal gas constant, R, in A is twice the value of R in B

(D) The temperature in A is four times as great as the temperature in B

(E) The gas in A is a heavier isotope than the gas in B

7. An ideal gas is heated in a closed container at constant volume. Which of the foll properties of the gas increases as the gas is heated?

(A) The atomic mass of the atoms in the molecules

(B) The number of molecules

(C) The density of the gas

(D) The pressure exerted by the molecules on the walls of the container

(E) The average space between the molecules

8. 24 J of heat are added to a gas in a container, and then the gas does 6 J of work on the of the container. What is the change in internal energy for the gas?

(A) –30 J

(B) –18 J

(C) 4 J

(D) 18 J

(E) 30 J

9. When water freezes, its molecules take on a more structured order. Why doesn’t this contr the Second Law of Thermodynamics?

(A) Because the density of the water is decreasing

(B) Because the water is gaining entropy as it goes from liquid to solid state

(C) Because the water’s internal energy is decreasing

(D) Because the surroundings are losing entropy

(E) Because the surroundings are gaining entropy

10. A heat engine produces 100 J of heat, does 30 J of work, and emits 70 J into a cold reser What is the efficiency of the heat engine?

(A) 100%

(B) 70%

(C) 42%

(D) 40%

(E) 30%

Explanations

1. **D**

The amount of heat lost by the hot water must equal the amount of heat gained by the cold water. Since all water has the same specific heat capacity, we can calculate the change in temperature of the cold water, ΔT_c, in terms of the change in temperature of the hot water, ΔT_h:

$$\begin{aligned} m_c c\Delta T_c &= m_h c\Delta T_h \\ \Delta T_c &= \frac{m_h}{m_c}\Delta T_h \\ &= 5\Delta T_h \end{aligned}$$

At thermal equilibrium, the hot water and the cold water will be of the same temperature. With this in mind, we can set up a formula to calculate the value of ΔT_h:

$$\begin{aligned} 65°\mathrm{C} - \Delta T_h &= 5°\mathrm{C} + \Delta T_c \\ 6\Delta T_h &= 60°\mathrm{C} \\ \Delta T_h &= 10°\mathrm{C} \end{aligned}$$

Since the hot water loses 10 C°, we can determine that the final temperature of the mixture is 65 °C - 10 C° = 55°C.

2. **D**

If a block of ice at 0°C is heated, it will begin to melt. The temperature will remain constant until the ice is completely transformed into liquid. The amount of heat needed to melt a certain mass of ice is given by the latent heat of fusion for water. The specific heat of water is only relevant when the temperature of the ice or water is changing, and the density of the water is not relevant.

3. **D**

Asphalt, like most materials, has a positive coefficient of linear expansion, meaning that it expands as temperatures rise in summer and shrinks as temperatures fall in winter. This effect is called the law of thermal expansion, **D**. The gaps in the sidewalk allow the blocks to expand without pushing against each other and cracking.

4. **E**

Convection is a form of heat transfer where a large number of molecules move from one place to another. An overhead fan works precisely by this method: it sends cooler air molecules down into a hot room, cooling the temperature of the room. The heat of the sun and the cooking action of a microwave are both forms of radiation, while the heat on a frying pan and the cooling action of ice cubes are both forms of conduction.

5. **A**

Since the gas is in a closed container, its volume remains constant, so the correct answer is **A**. When the gas is heated, its temperature increases, meaning that the average speed of the gas molecules increases. An increase in temperature also means there are more collisions between molecules. According to the ideal gas law, when volume is constant and temperature is increased, then pressure will also increase. Pressure is determined by the rate of collisions of the gas molecules with the walls of the container.

6. **A**

According to the ideal gas law, temperature is directly proportional to volume and pressure. Since the volume of the container is constant, that means that doubling the temperature will double the pressure.

R is a constant: it doesn't vary under different circumstances, so **C** is wrong. Also, we are looking at a random sample of the gas, so there won't be a heavier isotope in one or the other of the containers: **E** is also wrong.

7. **D**

The ideal gas law states that temperature is directly proportional to pressure and volume. Since the gas is in a closed container, the volume is fixed, so an increase in temperature leads to an increase in pressure. The correct answer is **D**.

The atomic mass and the number of molecules are fixed properties of the gas sample, and cannot change with heat. The density depends on the mass and the volume. The mass is also a fixed property of the gas sample, and the volume is being held constant, since we are dealing with a closed container. Therefore, the density must also remain constant. Because the number of molecules and the volume are constant, the average space between the molecules must remain constant.

8. **D**

The First Law of Thermodynamics tells us that $\Delta U = \Delta Q + \Delta W$: the change in internal energy is equal to the change in heat plus the work done on the system. The value of ΔQ is 24 J, since that much heat is added to the system, and the value of ΔW is –6 J, since the system *does* work rather than has work *done on it*. With this in mind, calculating ΔU is a simple matter of subtraction:

$$\Delta U = \Delta Q + \Delta W = 24\text{ J} - 6\text{ J}$$
$$= 18\text{ J}$$

9. **E**

The Second Law of Thermodynamics tells us that the total amount of disorder, or entropy, in the universe is increasing. The entropy in a particular system can decrease, as with water molecules when they turn to ice, but only if the entropy in the surroundings of that system increases to an equal or greater extent. The Second Law of Thermodynamics holds, but only because the surroundings are gaining entropy, so the correct answer is **E**. Answer **D** refers to the key part of the answer, but gives the wrong information about the change in entropy of the surroundings.

Be careful not to fall for answer **C**. This is an explanation for why the water does not lose heat when it freezes: it is, in fact, losing internal energy. This is an instance of the *First* Law of Thermodynamics, which states that the change in a system's internal energy is equal to the value of the heat transfer in the system minus the work done by the system.

10. **E**

The efficiency of a heat engine is defined as $e = 1 - \Delta Q_{out}/\Delta Q_{in}$, where ΔQ_{out} is the amount of heat output into the cold reservoir and ΔQ_{in} is the amount of heat produced by the heat engine. Plugging the numbers in the question into this formula, we find that:

$$e = 1 - \frac{70\text{ J}}{100\text{ J}} = 0.3$$

An efficiency of 0.3 is the same thing as 30%.

SAT Subject Physics Key Formulas

Centripetal Acceleration	$a_c = \frac{v^2}{r}$
Centripetal Force	$F = \frac{mv^2}{r}$
Newton's Law of Universal Gravitation	$F_g = G\frac{m_1 m_2}{r^2}$
Acceleration Due to Gravity at the Surface of a Planet	$a = G\frac{m_{\text{planet}}}{r^2}$
Velocity of a Satellite in Orbit	$v = \sqrt{\frac{Gm_e}{R}}$
Gravitational Potential Energy	$U = -G\frac{m_1 m_2}{r}$
Kinetic Energy of a Satellite in Orbit	$KE = G\frac{m_s m_e}{2R}$
Total Energy of a Satellite in Orbit	$E = -G\frac{m_s m_e}{2R}$
Kepler's Third Law	$\frac{T^2}{a^3} = \text{constant}$

Practice Questions

Questions 1 - 3 refer to a ball of mass *m* on a string of length *R*, swinging around in circular motion, with instantaneous velocity *v* and centripetal acceleration *a*.

1. What is the centripetal acceleration of the ball if the length of the string is doubl
   (A) $a/4$
   (B) $a/2$
   (C) a
   (D) $2a$
   (E) $4a$

2. What is the centripetal acceleration of the ball if the instantaneous velocity of the is doubled?

(A) $a/4$

(B) $a/2$

(C) a

(D) $2a$

(E) $4a$

3. What is the centripetal acceleration of the ball if its mass is doubled?

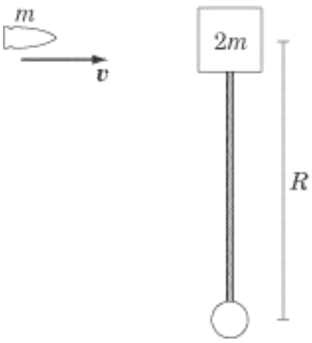
(A) $a/4$

(B) $a/2$

(C) a

(D) $2a$

(E) $4a$



4. A bullet of mass m traveling at velocity v strikes a block of mass $2m$ that is attached rod of length R. The bullet collides with the block at a right angle and gets stuck i block. The rod is free to rotate. What is the centripetal acceleration of the block afte collision?

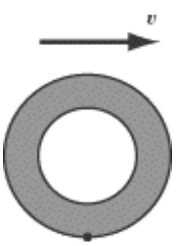
(A) v^2/R

(B) $(1/2)\ v^2/R$

(C) $(1/3)\ v^2/R$

(D) $(1/4)\ v^2/R$

(E) $(1/9)\ v^2/R$



5. A car wheel drives over a pebble, which then sticks to the wheel momentarily as the displaces it. What is the direction of the initial acceleration of the pebble?

(A) 

(B) 

(C) 

(D) 

(E) 

6. If we consider the gravitational force F between two objects of masses m_1 and m_2 respecti separated by a distance R, and we double the distance between them, what is the new magr of the gravitational force between them?

(A) $F/4$

(B) $F/2$

(C) F

(D) $2F$

(E) $4F$

7. If the Earth were compressed in such a way that its mass remained the same, but the dis around the equator were just one-half what it is now, what would be the acceleration c gravity at the surface of the Earth?

(A) $g/4$

(B) $g/2$

(C) g

(D) $2g$

(E) $4g$

8. A satellite orbits the Earth at a radius r and a velocity v. If the radius of its orb doubled, what is its velocity?

(A) $v/2$

(B) $v/\sqrt{2}$

(C) v

(D) $\sqrt{2}\,v$

(E) $2v$

9. An object is released from rest at a distance of $2r_e$ from the center of the Earth, wher
the radius of the Earth. In terms of the gravitational constant (G), the mass of the
(M), and r_e, what is the velocity of the object when it hits the Earth?

(A) $\sqrt{GM/r_e}$

(B) GM/r_e

(C) $\sqrt{GM/2r_e}$

(D) $GM/2r_e$

(E) $2GM/r_e$

10. Two planets, *A* and *B*, orbit a star. Planet *A* moves in an elliptical orbit whose semi axis has length *a*. Planet *B* moves in an elliptical orbit whose semimajor axis has a l of 9*a*. If planet *A* orbits with a period *T*, what is the period of planet *B*' s orbit?

(A) $729T$

(B) $27T$

(C) $3T$

(D) $T/3$

(E) $T/27$

Explanations

1. B

The equation for the centripetal acceleration is $a = v^2/r$. That is, acceleration is inversely proportional to the radius of the circle. If the radius is doubled, then the acceleration is halved.

2. E

From the formula $a = v^2/r$, we can see that centripetal acceleration is directly proportional to the square of the instantaneous velocity. If the velocity is doubled, then the centripetal acceleration is multiplied by a factor of 4.

3. C

The formula for centripetal acceleration is $a_c = v^2/r$. As you can see, mass has no influence on centripetal acceleration. If you got this question wrong, you were probably thinking of the formula for centripetal force: $F = mv^2/r$. Much like the acceleration due to gravity, centripetal acceleration is independent of the mass of the accelerating object.

4. E

The centripetal acceleration of the block is given by the equation $a = v'^2/R$, where v' is the velocity of the bullet-block system after the collision. We can calculate the value for v' by applying the law of conservation of linear momentum. The momentum of the bullet before it strikes the block is $p = mv$. After it strikes the block, the bullet-block system has a momentum of $p' = 3mv'$. Setting these two equations equal to one another, we find:

$$\begin{aligned} 3mv' &= mv \\ v' &= \frac{1}{3}v \end{aligned}$$

If we substitute $v' = (1/3)v$ into the equation $a = v'^2/R$, we find:

$$\begin{aligned} a &= \frac{v'^2}{R} \\ &= \frac{(\frac{1}{3}v)^2}{R} \\ &= \frac{1}{9}\frac{v^2}{R} \end{aligned}$$

5. C

The rotating wheel exerts a centripetal force on the pebble. That means that, initially, the pebble is drawn directly upward toward the center of the wheel.

6. A

Newton's Law of Universal Gravitation tells us that the gravitational force between two objects is directly proportional to the masses of those two objects, and inversely proportional to the square of the distance between them. If that distance is doubled, then the gravitational force is divided by four.

7. E

Circumference and radius are related by the formula $C = 2\pi r$, so if the circumference of the earth were halved, so would the radius. The acceleration due to gravity at the surface of the earth is given by the formula:

$$a = \frac{GM}{r^2}$$

where M is the mass of the earth. This is just a different version Newton's Law of Universal Gravitation, where both sides of the equation are divided by m, the mass of the falling object. From this formula, we can see that a is inversely proportional to r^2. If the value of a is normally g, the value of a when r is halved must be $4g$.

8. B

To get a formula that relates orbital velocity and orbital radius, we need to equate the formulas for gravitational force and centripetal force, and then solve for v:

$$\begin{aligned} \frac{mv^2}{r} &= \frac{GMm}{r^2} \\ v^2 &= \frac{GM}{r} \\ v &= \sqrt{\frac{GM}{r}} \end{aligned}$$

From this formula, we can see that velocity is inversely proportional to the square root of r. If

r is doubled, v is multiplied by $1/\sqrt{2}$.

9. A

We can apply the law of conservation of energy to calculate that the object's change in potential energy is equal to its change in kinetic energy. The potential energy of an object of mass m at a distance r_e from a planet of mass M is $U = -GMm/r$. The change in potential energy for the object is:

$$\Delta U = -G\frac{Mm}{2r_e} - -G\frac{Mm}{r_e} = -G\frac{Mm}{2r_e} + 2G\frac{Mm}{2r_e}$$
$$= G\frac{Mm}{2r_e}$$

This change in potential energy represents the object's total kinetic energy, $KE = {}^{1}/_{2}\, mv^2$, when it hits the Earth. Equating change in potential energy and total kinetic energy, we can solve for v:

$$\frac{1}{2}mv^2 = G\frac{Mm}{2r_e}$$
$$v^2 = \frac{GM}{r_e}$$
$$v = \sqrt{\frac{GM}{r_e}}$$

10. B

Kepler's Third Law tells us that T^2/a^3 is a constant for every planet in a system. If we let xT be the value for the period of planet B's orbit, then we can solve for x using a bit of algebra:

$$\frac{(xT)^2}{(9a)^3} = \frac{T^2}{a^3}$$
$$x^2T^2 = 9^3T^2$$
$$x^2 = (3^2)^3$$
$$= (3^3)^2$$
$$x = 3^3$$
$$= 27$$