## SAT Subject Physics Formula Reference

This guide is a compilation of about fifty of the most important physics formulas to know for the SAT Subject test in physics. (Note that formulas are *not* given on the test.) Each formula row contains a description of the variables or constants that make up the formula, along with a brief explanation of the formula.

### Kinematics

<table>
<thead>
<tr>
<th>Formula</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v_{\text{ave}} = \frac{\Delta x}{\Delta t} )</td>
<td>( v_{\text{ave}} = \text{average velocity} )  ( \Delta x = \text{displacement} )  ( \Delta t = \text{elapsed time} )  The definition of average velocity.</td>
</tr>
<tr>
<td>( v_{\text{ave}} = \frac{(v_i + v_f)}{2} )</td>
<td>( v_{\text{ave}} = \text{average velocity} )  ( v_i = \text{initial velocity} )  ( v_f = \text{final velocity} )  Another definition of the average velocity, which works when ( a ) is constant.</td>
</tr>
<tr>
<td>( a = \frac{\Delta v}{\Delta t} )</td>
<td>( a = \text{acceleration} )  ( \Delta v = \text{change in velocity} )  ( \Delta t = \text{elapsed time} )  The definition of acceleration.</td>
</tr>
<tr>
<td>( \Delta x = v_i \Delta t + \frac{1}{2} a(\Delta t)^2 )</td>
<td>( \Delta x = \text{displacement} )  ( v_i = \text{initial velocity} )  ( \Delta t = \text{elapsed time} )  ( a = \text{acceleration} )  Use this formula when you don’t have ( v_f ).</td>
</tr>
<tr>
<td>( \Delta x = v_f \Delta t - \frac{1}{2} a(\Delta t)^2 )</td>
<td>( \Delta x = \text{displacement} )  ( v_f = \text{final velocity} )  ( \Delta t = \text{elapsed time} )  ( a = \text{acceleration} )  Use this formula when you don’t have ( v_i ).</td>
</tr>
</tbody>
</table>
## Kinematics (continued)

\[ v_f^2 = v_i^2 + 2a\Delta x \]

- \(v_f\) = final velocity
- \(v_i\) = initial velocity
- \(a\) = acceleration
- \(\Delta x\) = displacement

Use this formula when you don’t have \(\Delta t\).

## Dynamics

\[ F = ma \]

- \(F\) = force
- \(m\) = mass
- \(a\) = acceleration

Newton’s Second Law. Here, \(F\) is the net force on the mass \(m\).

\[ W = mg \]

- \(W\) = weight
- \(m\) = mass
- \(g\) = acceleration due to gravity

The weight of an object with mass \(m\). This is really just Newton’s Second Law again.

\[ f = \mu N \]

- \(f\) = friction force
- \(\mu\) = coefficient of friction
- \(N\) = normal force

The “Physics is Fun” equation. Here, \(\mu\) can be either the kinetic coefficient of friction \(\mu_k\) or the static coefficient of friction \(\mu_s\).

\[ p = mv \]

- \(p\) = momentum
- \(m\) = mass
- \(v\) = velocity

The definition of momentum. It is conserved (constant) if there are no external forces on a system.
## Dynamics (continued)

<table>
<thead>
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<tbody>
<tr>
<td>( \Delta p = F \Delta t )</td>
<td>( \Delta p ) = change in momentum, ( F ) = applied force, ( \Delta t ) = elapsed time, ( F \Delta t ) is called the impulse.</td>
</tr>
</tbody>
</table>

## Work, Energy, and Power

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>( W = Fd \cos \theta ) or ( W = F_\parallel d )</td>
<td>( W ) = work, ( F ) = force, ( d ) = distance, ( \theta ) = angle between ( F ) and the direction of motion, ( F_\parallel ) = parallel force. Work is done when a force is applied to an object as it moves a distance ( d ). ( F_\parallel ) is the component of ( F ) in the direction that the object is moved.</td>
</tr>
<tr>
<td>( KE = \frac{1}{2}mv^2 )</td>
<td>( KE ) = kinetic energy, ( m ) = mass, ( v ) = velocity. The definition of kinetic energy for a mass ( m ) with velocity ( v ).</td>
</tr>
<tr>
<td>( PE = mgh )</td>
<td>( PE ) = potential energy, ( m ) = mass, ( g ) = acceleration due to gravity, ( h ) = height. The potential energy for a mass ( m ) at a height ( h ) above some reference level.</td>
</tr>
</tbody>
</table>
### Work, Energy, Power (continued)

<table>
<thead>
<tr>
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</table>
| \[ W = \Delta(KE) \] | \[ W = \text{work done} \]  
\[ KE = \text{kinetic energy} \]  
The “work-energy” theorem: the work done by the net force on an object equals the change in kinetic energy of the object. |
| \[ E = KE + PE \] | \[ E = \text{total energy} \]  
\[ KE = \text{kinetic energy} \]  
\[ PE = \text{potential energy} \]  
The definition of total (“mechanical”) energy. If there is no friction, it is conserved (stays constant). |
| \[ P = \frac{W}{\Delta t} \] | \[ P = \text{power} \]  
\[ W = \text{work} \]  
\[ \Delta t = \text{elapsed time} \]  
Power is the amount of work done per unit time (i.e., power is the rate at which work is done). |

### Circular Motion

<table>
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</table>
| \[ a_c = \frac{v^2}{r} \] | \[ a_c = \text{centripetal acceleration} \]  
\[ v = \text{velocity} \]  
\[ r = \text{radius} \]  
The “centripetal” acceleration for an object moving around in a circle of radius \( r \) at velocity \( v \). |
| \[ F_c = \frac{mv^2}{r} \] | \[ F_c = \text{centripetal force} \]  
\[ m = \text{mass} \]  
\[ v = \text{velocity} \]  
\[ r = \text{radius} \]  
The “centripetal” force that is needed to keep an object of mass \( m \) moving around in a circle of radius \( r \) at velocity \( v \). |
Circular Motion (continued)

<table>
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<tr>
<td>( v = \frac{2\pi r}{T} )</td>
<td>( v = ) velocity, ( r = ) radius, ( T = ) period. This formula gives the velocity ( v ) of an object moving once around a circle of radius ( r ) in time ( T ) (the period).</td>
</tr>
<tr>
<td>( f = \frac{1}{T} )</td>
<td>( f = ) frequency, ( T = ) period. The frequency is the number of times per second that an object moves around a circle.</td>
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Torques and Angular Momentum

<table>
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<tr>
<td>( \tau = rF \sin \theta ) or ( \tau = rF_\perp )</td>
<td>( \tau = ) torque, ( r = ) distance (radius), ( F = ) force, ( \theta = ) angle between ( F ) and the lever arm, ( F_\perp = ) perpendicular force. Torque is a force applied at a distance ( r ) from the axis of rotation. ( F_\perp = F \sin \theta ) is the component of ( F ) perpendicular to the lever arm.</td>
</tr>
<tr>
<td>( L = mvr )</td>
<td>( L = ) angular momentum, ( m = ) mass, ( v = ) velocity, ( r = ) radius. Angular momentum is conserved (i.e., it stays constant) as long as there are no external torques.</td>
</tr>
</tbody>
</table>
## Springs

<table>
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<tr>
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</table>
| $F_s = kx$ | $F_s$ = spring force  
$k$ = spring constant  
$x$ = spring stretch or compression  
“Hooke’s Law”. The force is opposite to the stretch or compression direction. |

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| $PE_s = \frac{1}{2}kx^2$ | $PE_s$ = potential energy  
$k$ = spring constant  
$x$ = amount of spring stretch or compression  
The potential energy stored in a spring when it is either stretched or compressed. Here, $x = 0$ corresponds to the “natural length” of the spring. |

## Simple Harmonic Motion

<table>
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| $T_s = 2\pi \sqrt{\frac{m}{k}}$ | $T_s$ = period of motion  
$k$ = spring constant  
$m$ = attached mass  
The period of the simple harmonic motion of a mass $m$ attached to an ideal spring with spring constant $k$. |

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| $T_p = 2\pi \sqrt{\frac{l}{g}}$ | $T_p$ = period of motion  
l = pendulum length  
g = acceleration due to gravity  
The period of the simple harmonic motion of a mass $m$ on an ideal pendulum of length $l$. |
### Gravity

\[
F_g = G \frac{m_1 m_2}{r^2}
\]

- \(F_g\): force of gravity
- \(G\): a constant
- \(m_1, m_2\): masses
- \(r\): distance of separation

Newton’s Law of Gravitation: this formula gives the attractive force between two masses a distance \(r\) apart.

### Electric Fields and Forces

\[
F = k \frac{q_1 q_2}{r^2}
\]

- \(F\): electric force
- \(k\): a constant
- \(q_1, q_2\): charges
- \(r\): distance of separation

“Coulomb’s Law”. This formula gives the force of attraction or repulsion between two charges a distance \(r\) apart.

\[
F = qE
\]

- \(F\): electric force
- \(E\): electric field
- \(q\): charge

A charge \(q\), when placed in an electric field \(E\), will feel a force on it, given by this formula (\(q\) is sometimes called a “test” charge, since it tests the electric field strength).

\[
E = k \frac{q}{r^2}
\]

- \(E\): electric field
- \(k\): a constant
- \(q\): charge
- \(r\): distance of separation

This formula gives the electric field due to a charge \(q\) at a distance \(r\) from the charge. Unlike the “test” charge, the charge \(q\) here is actually generating the electric field.
**Electric Fields and Forces (continued)**

<table>
<thead>
<tr>
<th>Formula</th>
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</table>
| \( U_E = k \frac{q_1 q_2}{r} \) | \( U_E \) = electric PE  
\( k \) = a constant  
\( q_1, q_2 \) = charges  
\( r \) = distance of separation  
This formula gives the electric potential energy for two charges a distance \( r \) apart. For more than one pair of charges, use this formula for each pair, then add all the \( U_E \)'s. |
| \( \Delta V = \frac{-W_E}{q} = \frac{\Delta U_E}{q} \) | \( \Delta V \) = potential difference  
\( W_E \) = work done by E field  
\( U_E \) = electric PE  
\( q \) = charge  
The potential difference \( \Delta V \) between two points is defined as the negative of the work done by the electric field per unit charge as charge \( q \) moves from one point to the other. Alternately, it is the change in electric potential energy per unit charge. |
| \( V = k \frac{q}{r} \) | \( V \) = electric potential  
\( k \) = a constant  
\( q \) = charge  
\( r \) = distance of separation  
This formula gives the electric potential due to a charge \( q \) at a distance \( r \) from the charge. For more than one charge, use this formula for each charge, then add all the \( V \)'s. |
| \( E = \frac{V}{d} \) | \( E \) = electric field  
\( V \) = voltage  
\( d \) = distance  
Between two large plates of metal separated by a distance \( d \) which are connected to a battery of voltage \( V \), a uniform electric field between the plates is set up, as given by this formula. |

**Circuits**

<table>
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</table>
| \( V = IR \) | \( V \) = voltage  
\( I \) = current  
\( R \) = resistance  
“Ohm’s Law”. This law gives the relationship between the battery voltage \( V \), the current \( I \), and the resistance \( R \) in a circuit. |
### Circuits (continued)

<table>
<thead>
<tr>
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</table>
| $P = IV$ | $P = power$  
$or$  
$P = V^2 / R$ | $I = current$  
$V = voltage$  
$R = resistance$  
All of these power formulas are equivalent and give the power used in a circuit resistor $R$. Use the formula that has the quantities that you know. |
| $R_s = \frac{1}{R_1 + R_2 + \ldots}$ | $R_s = total (series)$ resistance  
$R_1 = first\ resistor$  
$R_2 = second\ resistor$  
$\ldots$  
When resistors are placed end to end, which is called “in series”, the effective total resistance is just the sum of the individual resistances. |
| $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$ | $R_p = total (parallel)$ resistance  
$R_1 = first\ resistor$  
$R_2 = second\ resistor$  
$\ldots$  
When resistors are placed side by side (or “in parallel”), the effective total resistance is the inverse of the sum of the reciprocals of the individual resistances (whew!). |
| $q = CV$ | $q = charge$  
$C = capacitance$  
$V = voltage$  
This formula is “Ohm’s Law” for capacitors. Here, $C$ is a number specific to the capacitor (like $R$ for resistors), $q$ is the charge on one side of the capacitor, and $V$ is the voltage across the capacitor. |
# Magnetic Fields and Forces

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<tbody>
<tr>
<td>( F = ILB \sin \theta )</td>
<td>This formula gives the force on a wire carrying current ( I ) while immersed in a magnetic field ( B ). Here, ( \theta ) is the angle between the direction of the current and the direction of the magnetic field (( \theta ) is usually 90°, so that the force is ( F = ILB )).</td>
</tr>
</tbody>
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<tbody>
<tr>
<td>( F = qvB \sin \theta )</td>
<td>The force on a charge ( q ) as it travels with velocity ( v ) through a magnetic field ( B ) is given by this formula. Here, ( \theta ) is the angle between the direction of the charge's velocity and the direction of the magnetic field (( \theta ) is usually 90°, so that the force is ( F = qvB )).</td>
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</tbody>
</table>

# Waves and Optics

<table>
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<tbody>
<tr>
<td>( v = \lambda f )</td>
<td>This formula relates the wavelength and the frequency of a wave to its speed. The formula works for both sound and light waves.</td>
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<tr>
<td>( v = \frac{c}{n} )</td>
<td>When light travels through a medium (say, glass), it slows down. This formula gives the speed of light in a medium that has an index of refraction ( n ). Here, ( c = 3.0 \times 10^8 ) m/s.</td>
</tr>
</tbody>
</table>
**Waves and Optics (continued)**

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

- \( n_1 \) = incident index
- \( \theta_1 \) = incident angle
- \( n_2 \) = refracted index
- \( \theta_2 \) = refracted angle

“Snell’s Law”. When light moves from one medium (say, air) to another (say, glass) with a different index of refraction \( n \), it changes direction (refracts). The angles are taken from the normal (perpendicular).

\[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \]

- \( d_o \) = object distance
- \( d_i \) = image distance
- \( f \) = focal length

This formula works for lenses and mirrors, and relates the focal length, object distance, and image distance.

\[ m = -\frac{d_i}{d_o} \]

- \( m \) = magnification
- \( d_i \) = image distance
- \( d_o \) = object distance

The magnification \( m \) is how much bigger (\(|m| > 1\)) or smaller (\(|m| < 1\)) the image is compared to the object. If \( m < 0 \), the image is inverted compared to the object.

**Heat and Thermodynamics**

\[ Q = mc \Delta T \]

- \( Q \) = heat added or removed
- \( m \) = mass of substance
- \( c \) = specific heat
- \( \Delta T \) = change in temperature

The specific heat \( c \) for a substance gives the heat needed to raise the temperature of a mass \( m \) of that substance by \( \Delta T \) degrees. If \( \Delta T < 0 \), the formula gives the heat that has to be removed to lower the temperature.
### Heat and Thermodynamics (continued)

<table>
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</thead>
<tbody>
<tr>
<td>( Q = ml )</td>
<td>( Q = ) heat added or removed, ( m = ) mass of substance, ( l = ) specific heat of transformation. When a substance undergoes a change of phase (for example, when ice melts), the temperature doesn’t change; however, heat has to be added (ice melting) or removed (water freezing). The specific heat of transformation ( l ) is different for each substance.</td>
</tr>
<tr>
<td>( \Delta U = Q - W )</td>
<td>( \Delta U = ) change in internal energy, ( Q = ) heat added, ( W = ) work done by the system. The “first law of thermodynamics”. The change in internal energy of a system is the heat added minus the work done by the system.</td>
</tr>
<tr>
<td>( E_{\text{eng}} = \frac{W}{Q_{\text{hot}}} \times 100 )</td>
<td>( E_{\text{eng}} = % ) efficiency of the heat engine, ( W = ) work done by the engine, ( Q_{\text{hot}} = ) heat absorbed by the engine. A heat engine essentially converts heat into work. The engine does work by absorbing heat from a hot reservoir and discarding some heat to a cold reservoir. The formula gives the quality (“efficiency”) of the engine.</td>
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### Pressure and Gases

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<tr>
<td>( P = \frac{F}{A} )</td>
<td>( P = ) pressure, ( F = ) force, ( A = ) area. The definition of pressure. ( P ) is a force per unit area exerted by a gas or fluid on the walls of the container.</td>
</tr>
</tbody>
</table>
### Pressure and Gases (continued)

\[
\frac{PV}{T} = \text{constant}
\]

- **\( P \)** = pressure
- **\( V \)** = volume
- **\( T \)** = temperature

The “Ideal Gas Law”. For “ideal” gases (and also for real-life gases at low pressure), the pressure of the gas times the volume of the gas divided by the temperature of the gas is a constant.

### Modern Physics and Relativity

\[
E = hf
\]

- **\( E \)** = photon energy
- **\( h \)** = a constant
- **\( f \)** = wave frequency

The energy of a photon is proportional to its wave frequency; \( h \) is a number called “Planck’s constant”.

\[
\text{KE}_{\text{max}} = hf - \phi
\]

- **\( \text{KE}_{\text{max}} \)** = max kinetic energy
- **\( h \)** = a constant
- **\( f \)** = light frequency
- **\( \phi \)** = work function of the metal

The “photoelectric effect” formula. If light of frequency \( f \) is shined on a metal with “work function” \( \phi \), and \( hf > \phi \), then electrons are emitted from the metal. The electrons have kinetic energies no greater than \( \text{KE}_{\text{max}} \).

\[
\lambda = \frac{h}{p}
\]

- **\( \lambda \)** = matter wavelength
- **\( h \)** = a constant
- **\( p \)** = momentum

A particle can act like a wave with wavelength \( \lambda \), as given by this formula, if it has momentum \( p \). This is called “wave-particle” duality.

\[
\gamma = \frac{1}{\sqrt{1 - (v/c)^2}}
\]

- **\( \gamma \)** = the relativistic factor
- **\( v \)** = speed of moving observer
- **\( c \)** = speed of light

The relativistic factor \( \gamma \) is the amount by which moving clocks slow down and lengths contract, as seen by an observer compared to those of another observer moving at speed \( v \) (note that \( \gamma \geq 1 \)).