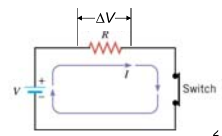
Review for Test 2

Ohm's Law

Ohm's law states that the current I flowing through a piece of material is proportional to the voltage ΔV applied across the material. The ***resistance*** (R) is defined as the ratio of ΔV to I.

$$\frac{\Delta V}{I} = R = \text{constant}$$
$$\Delta V = IR$$

Circuit diagram of the flashlight, and illustration of the variations in Ohm's Law:



The SI unit of Resistance is Volts/Ampere (V/A) or Ohms (Ω).

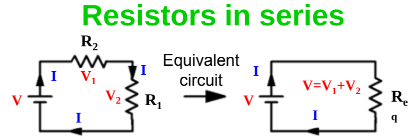
Electric Power (cont'd)

The power derived above, $P = I\Delta V$ is the power that must be delivered to an object in order to support the flow of current I through that object while maintaining a voltage of ΔV across it.

Below are alternative expressions for power, depending on whether the voltage or the current is known:

$$P = I\Delta V = \left(\frac{\Delta V}{R}\right)\Delta V = \frac{\Delta V^2}{R}$$
$$P = I\Delta V = I(IR) = I^2 R$$

Resistors in series



When resistors are in series they are arranged in a chain, the current has only one path to take.

So, the current is the same through each resistor in series.

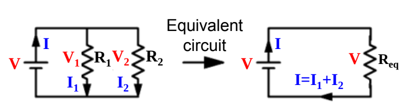
At the same time, the sum of the potential drops across each resistor must equal to the total potential drop of the voltage supply across the whole chain, i.e., the voltage supply's emf, V. Thus, $V = V_1 + V_2 \Rightarrow IR_{eq} = IR_1 + IR_2 \Rightarrow R_{eq} = R_1 + R_2$.

We can generalize the above result to any number of resistors, so the equivalent resistance of resistors in series is: $R_{eq} = R_1+R_2+R_3+\ldots$ and the loop rule is: $V = V_1+V_2+V_3+\ldots$

Resistors in parallel

When resistors are arranged in parallel, the current has multiple paths to take. Nevertheless, the currents of different paths must add to equal the total current entering the parallel combination, i.e., $I_1 + I_2 = I$. At the same time, each resistor is connected completely across the voltage supply. So, the potential difference across each resistor is the same equal to the emf of the voltage supply, $V_1 = V_2 = V$.

$$I = I_1 + I_2$$
$$\Rightarrow \frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2}$$



For more than two resistors connected in parallel,

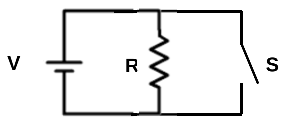
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

The next questions make use of the following equations:

$R_{eq} = R_1 + R_2 + R_3 + \ldots$ $\quad$ $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

Current: $I = \frac{\Delta Q}{\Delta t}$ $\quad$ Ohm's Law: $\Delta V = IR$ $\quad$ Power: $P = VI = I^2R = V^2/R$

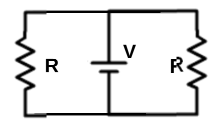
0a. Adding an open circuit in parallel



Question: What is the equivalent resistance of the above parallel connection if switch S is open?

Ans. $R_{eq} = R$

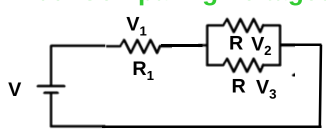
0b. Adding an open switch in parallel



Question: What is the equivalent resistance of the circuit?

Ans. $R_{eq} = R/2$

0c. Comparing Voltages

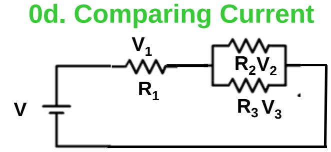


If $R_1 = R/2$, rank the voltages V_1, V_2 and V_3.

1. $V_1 = V_2 = V_3$
2. $V_1 > V_2 > V_3$
3. $V_1 > V_2 = V_3$
4. $V_3 = V_2 > V_1$

Ans. Number 1. First, $V_2 = V_3$ because they are voltages across resistors connected in parallel. Secondly, their equivalent resistance is R/2. Because R_1 is also R/2, R_1 and the parallel connection should split V equally, i.e., the voltages V_1, V_2, V_3 should all be V/2.

0d. Comparing Current

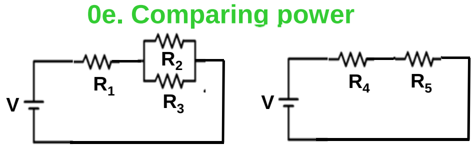


In the above, if we take away R_2, the current through R_1 will…

1. increase
2. decrease
3. make no change
4. There is insufficient information to tell.

Ans. Number 2. Taking R2 away will increase the equivalent resistance of the parallel connection. This will cause the total resistance of the circuit to increase, so will cause the total current, which is the same current passing through R_1, to decrease.

0e. Comparing power



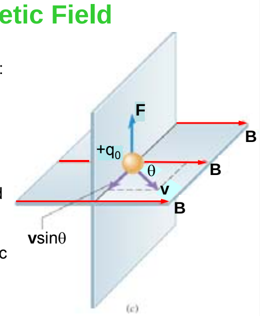
Suppose that all the resistors R_1, …, to R_5 are the same. Select the statement that is correct.

1. R1 has the biggest power and the power through R4 is equal that of R5 and is the lowest.
2. The power through R2 is the same as R3 and is higher than that of R5 and R4.
3. The power through R2 is the same as that through R3 is the lowest of all.

Forces on a Moving Charge Particle due to a Magnetic Field

The Lorentz or magnetic force is given by:

$F = qvB\sin\theta$

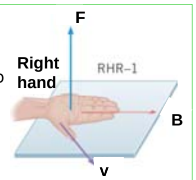


where q is the charge of the particle, v is the particle's speed, B is the magnetic field and θ is the angle between the ***B*** and ***v*** vector. In SI units, magnetic fields are in ***Tesla***. As an example, the earth's magnetic field is about 10^{-4} Tesla in the vicinity of its surface.

The direction of the Lorentz force is determined by a ***right-hand rule*** (RHR). In this class note, we refer to this right-hand rule as ***RHR-1***. Later in this chapter, we will encounter another RHR!

Right Hand Rule No. 1

Right Hand Rule No. 1. (RHR-1) Extend the right hand so the fingers point along the direction of the magnetic field and the thumb points along the velocity of the charge. The palm of the hand then faces in the direction of the magnetic force that acts on a positive charge.



If the moving charge is negative, the direction of the force is opposite to that predicted by RHR-1.

Notes:
(1) ***F*** is always perpendicular to both ***B*** and ***v***.
(2) This rule works even when ***v*** is not exactly perpendicular to ***B***.
(3) Details of this RHR is different from that adopted in Essential Physics but it gives the same result.

The next two examples make use of the following equations in the equation sheet:

Circular motion: $a_c = v^2/R$ $\quad T = \frac{2\pi R}{v}$

Magnetic Force: $|F| = |qvB\sin\theta|$

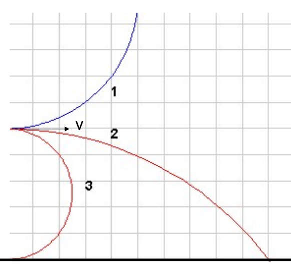
Note: To do these problems, you need to be able to do the following derivation based on these equations:

$$F = qvB = \frac{mv^2}{r}$$

$$\Rightarrow r = \frac{mv}{qB}$$

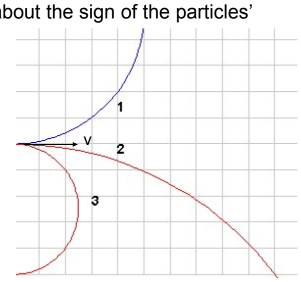
1. Below are the trajectories of three charged objects with the same mass and the same magnitude charge moving through a region of uniform magnetic field. Rank the objects based on their speeds.

1. 1 > 2 > 3
2. 2 > 1 > 3
3. 3 > 2 > 1
4. 3 > 1 > 2
5. Cannot tell



2. Below are the trajectories of three charged objects with the same mass and the same magnitude charge moving through a region of uniform magnetic field. The magnetic field is pointing out of the page. Which of the following are correct about the sign of the particles' charge?

1. Only 1 is negative.
2. Only 2 is negative.
3. Only 3 is negative.
4. Only 2 and 3 are negative.
5. All are negative.
6. Cannot tell



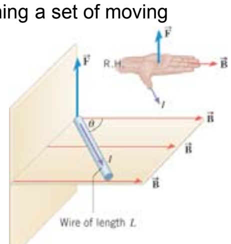
The force on a current-carrying wire

A magnetic field exerts a force $F = qvB\sin\theta$ on a single moving charge, so it's not surprising that it exerts a force on a current-carrying wire, seen as containing a set of moving charges. Using $q = I\,t$, the force is:

$$F = IvtB\sin\theta$$

In the above, the charge, q, moves through the wire in time t. So, $vt = L$, the length of the wire and

$$\boxed{F = ILB\sin\theta}$$



The direction of the force is given by RHR-1, where your thumb points in the direction of the current. Current is defined to be the direction of flow of positive charges, so your right hand always gives the correct direction.

The magnetic field from a long straight wire

The long straight current-carrying wire, for magnetism, is analogous to the point charge for electric fields.

The magnetic field at a distance r from a wire with current I is:

$$B = \frac{\mu_0 I}{2\pi r}$$

μ_0, the permeability of free space, is:

$$\mu_0 = 4\pi \times 10^{-7}\ \text{Tm/A}$$

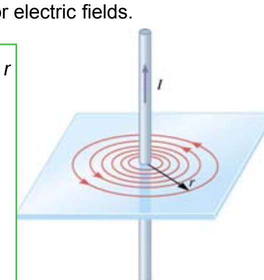
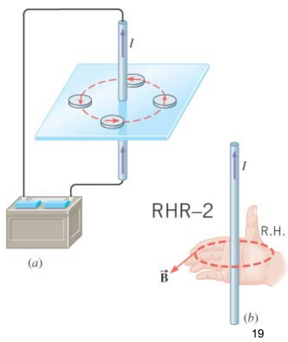


Figure above shows the field lines about a current-carrying straight wire.

The magnetic field from a long straight wire

The direction of the field follows another right-hand rule:

Right-Hand Rule No. 2. (RHR-2)
Curl the fingers of the right hand into the shape of a half-circle. Point the thumb in the direction of the conventional current, and the tips of the fingers will point in the direction of the magnetic field.



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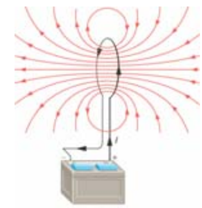
The field from a circular current loop

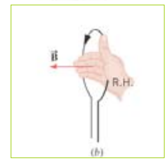
At the center of the circular loop, the magnetic field is:

$$B = \frac{\mu_o I}{2R}$$

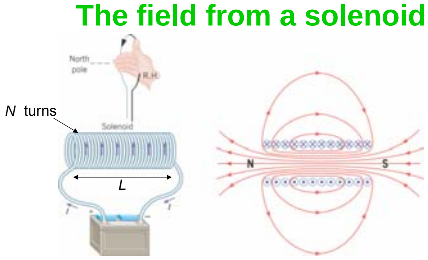
where R is the radius of the loop.



The above shows that the field lines around the loop resemble those from a bar magnet. The direction of the magnetic field can be determined by yet **another RHR** as shown at right.



The field from a solenoid



For a solenoid of length *L*, current *I*, and total number of turns *N*, the magnetic field inside the solenoid is given by:

$$B = \frac{\mu_0 NI}{L}$$

The direction of the magnetic field is determined by the <u>same RHR</u> that determines the direction of the magnetic field in a current loop.

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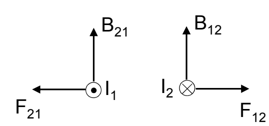
The force between two wires

It is straightforward to show that the force on wire one due to the field, B_{21}, produced by the current in wire 2 causes a magnet force in wire one, F_{21} that has the same magnitude but opposite direction to that of F_{12}.



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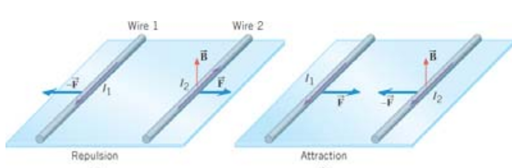
The force between two wires

In this situation, opposites repel and likes attract!
Parallel currents going the same direction attract.
If they are in opposite directions they repel.



Make sure that you can see why B is pointing up at where wire 2 is!

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The next four examples make use of the following circled equations in the equation sheet:

Magnetic Force: $|F| = |qvB\sin\theta|$ $\quad |F| = |ILB\sin\theta|$

Generating magnetic field: $B = \frac{\mu_0 I}{2\pi r}$ (wire) $\quad B = \frac{\mu_0 I}{2r}$ (loop)

$B = \frac{\mu_0 NI}{l}$ (solenoid)

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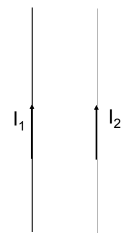
5. The figure shows two current-carrying wires separated by a distance of 1 mm and the same length of 30 cm. Further, I_1 = 1A and I_2 = 2A. Which of the following statements are correct about the forces between the wires?

1. The forces can be calculated and they are attractive.
2. The forces can be calculated and they are repulsive.
3. The forces are attractive, but there is insufficient information to tell the magnitude of the forces.
4. The forces are repulsive, but there is insufficient information to tell the magnitude of the forces.



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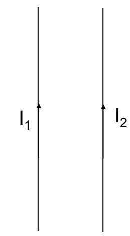
6. The figure shows two current-carrying wires with I_1 = 1 A and I_2 = 2A. Which of the following statements is correct about the forces between the wires?

1. The force on wire 2 is bigger than that on wire 1.
2. The forces on wire 1 and 2 are the same.



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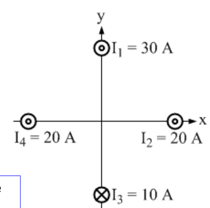
7. In which direction is the net magnetic field at the origin in the situation shown below? All the wires are the same distance from the origin.

1. Left
2. Right
3. Up
4. Down
5. Into the page
6. Out of the page
7. The net field is zero



Hint: Fill out the following for the fields B_i at the origin due to individual currents I_i :

Direction of B_1 is: →
Direction of B_2 is: down
Direction of B_3 is: →
Direction of B_4 is: up

The ranking of the B_i's is: $B_1 > B_2 = B_4 > B_3$

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8. A solenoid is 10 cm long and contains 100 turns. What is the B field inside the solenoid when a current of 1 A is applied? (Use $\mu_0 = 4\pi \times 10^{-7}$ N/A^2)

1. 12.57 T
2. 1.257 T
3. 0.1257 T
4. 0.01257 T
5. 0.001257 T
6. 0.0001257 T

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Magnetic Flux

Magnetic flux is a measure of the number of magnetic field lines passing through an area, *A*. The equation for magnetic flux, Φ, is:

$\Phi = BA\cos\theta$

where B is the magnetic field and θ is the angle between the ***B*** vector and the area vector, ***A***.

The SI unit for magnetic flux is the weber (Wb).
1 Wb = 1 Tm^2

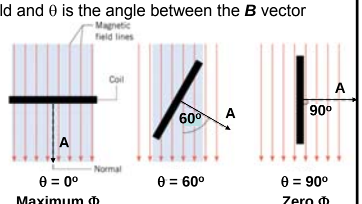

Figure. Illustration of how the magnetic flux through a coil varies with the angle θ.

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Faraday's Law

Faraday's Law says that the emf induced in a coil of *N* turns is given by the rate of change of the magnetic flux in the coil:

Faraday's Law: $\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$

Since $\Phi = BA\cos\theta$, the magnetic flux changes if any of *B*, *A* or θ changes. Faraday's law has important applications in the generation and distribution of electricity.

We call the voltage induced by a changing magnetic flux an induced emf. In other words, changing magnetic flux acts like a battery in a coil or loop, and a current flows when there's a complete circuit.

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Lenz's Law

Faraday's law tells you that there will be an induced emf in a circuit if the magnetic flux it is linking changes. Faraday's law also tells you the magnitude of the induced emf. But Lenz's Law tells you the direction of the emf:

Lenz's Law: A changing magnetic flux induces an emf that produces a current which sets up a magnetic field that ***tends to oppose whatever produced the change***.

Coils and loops do not like any change in the magnetic flux they are linking, and they will try to produce an emf or current to counteract the change imposed on them. Note that the net result is that they usually would not be successful - the change in the magnetic flux still takes place. This tendency to oppose the change is why there is a minus sign in Faraday's Law.

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A pictorial approach to Lenz's Law

Example: A wire loop in the plane of the page is in a uniform magnetic field directed into the page. Over some time interval the field is doubled. What direction is the induced current in the loop while the field is changing?

Step 1: Draw a "Before" picture, showing the field passing through the loop before the change takes place.

Step 2: Draw an "After" picture, showing the field passing through the loop after the change.

Step 3: Draw a "To Oppose" picture, showing the direction of the field the loop creates to oppose the change.

Step 4: Use the right-hand rule to determine which way the induced current goes in the loop to create that field.

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The next example make use of the following circled equations in the equation sheet:

Magnetic Flux: $\Phi_B = BA\cos\theta$

Faraday's Law: $\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$ Motional emf: $|\varepsilon| = vBL$

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The next 4 examples make use of the pictorial method.

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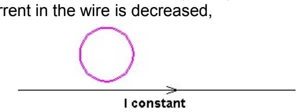
9. A wire loop is located near a long straight current-carrying wire. If the current in the wire is decreased,



1. The induced current in the loop would be clockwise.
2. The induced current in the loop would be counter-clockwise.
3. There will be no induced current in the loop.

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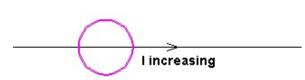
10. The loop is now placed directly on the wire with the wire bisecting the loop. If the current in the wire is increasing, in what direction is the induced current in the loop?

1. The induced current is clockwise.
2. The induced current is counter-clockwise.
3. There is no induced current.



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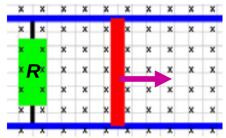
11. If the rod (in red) is moved to the right, will there be an induced current? If so, in what direction is it?



1. Clockwise
2. Counterclockwise
3. There is no induced current

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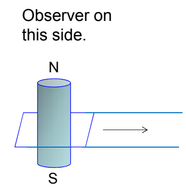
8. If the right edge of the rectangular circuit loop is steadily moved to the right, what is the direction of current induced in the loop, for an observer looking from the north pole?



1. Clockwise
2. Counter-clockwise

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Describing the motion at ALL points of a wave

So, for a wave traveling right, if we say the motion of the particle at x = 0 is given by:

$$y(0,t) = A\sin(\omega t)$$

The motion of a particle at another x-value is:

$$\boxed{y(x,t) = A\sin(\omega t - kx) \quad \text{(Right-traveling wave)}}$$

where k is a constant known as the wave number.

Note: this k is not the spring constant.

This one equation describes the whole wave.

Similarly, for a wave traveling left, the motion of the particle at position x is:

$$\boxed{y(x,t) = A\sin(\omega t + kx) \quad \text{(Left-traveling wave)}}$$

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The next three questions make use of these equations and concepts:

Waves: $y(x,t) = A\sin(kx \pm \omega t + \phi)$ $\quad k = \frac{2\pi}{\lambda}$ $\quad \omega = \frac{2\pi}{T}$ $\quad v = f\lambda$

Waves on a string: $v = \left(\frac{T}{\mu}\right)^{1/2}$

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14. Which of the following determines the wave speed of a wave on a string?

1. the frequency at which the end of the string is shaken up and down
2. the coupling between neighboring parts of the string, as measured by the tension in the string
3. the mass of each little piece of string, as characterized by the mass per unit length of the string.
4. Both 1 and 2
5. Both 1 and 3
6. Both 2 and 3
7. All three.

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Making use of the mathematical description

$$y(x,t) = (0.9\text{ cm})\sin\left[(5.0\text{ s}^{-1})t - (1.2\text{ m}^{-1})x\right]$$

Which of the following is the closest to the wave's wavelength?

1. 0.52 m
2. 1.2 m
3. 1.26 m
4. 5 m
5. 5.24 m

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Making use of the mathematical description

$$y(x,t) = (0.9 \text{ cm})\sin\left[(5.0 \text{ s}^{-1})t - (1.2 \text{ m}^{-1})x\right]$$

Which of the following is the closest to the wave's frequency in Hz?

1. 0.52 Hz
2. 0.8 Hz
3. 1.2 Hz
4. 5 Hz
5. 5.24 Hz

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Making use of the mathematical description

$$y(x,t) = (0.9 \text{ cm})\sin\left[(5.0 \text{ s}^{-1})t - (1.2 \text{ m}^{-1})x\right]$$

Which of the following is the closest to the wave's speed?

1. 0.0004 m/s
2. 0.004 m/s
3. 0.04 m/s
4. 0.4 m/s
5. 4 m/s

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The Doppler Effect in general

In some situations, both the source and the observer move. The general Doppler equation combines the previous results.

$$f' = f\left(\frac{v \pm v_o}{v \mp v_s}\right)$$

This, exact same equation is given in the equation sheet

Use the upper signs when the source and observer are approaching each other, and the lower signs when they are moving away from each another.

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18a. Let's say you, the observer, move toward a stationary source with speed v_o. For you, what change in the wave?

A. Their speed relative to you
B. Their wavelength
C. Their frequency

1. A and B only.
2. A and C only.
3. B and C only.
4. All

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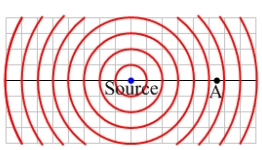
When the source doesn't move, there is no change in the wave pattern. So, the wavelength remains the same. But the apparent speed of the wave is changed to v + v_o if the source is approaching an observer or to v - v_o if the source is leaving an observer. The new frequency is the apparent wave speed divided by the wavelength.



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18. You, a stationary observer, are near a source that is moving with speed v_s. What change, in effect, for the waves as seen by you?

A. Their speed relative to you
B. Their wavelength
C. Their frequency

1. A and B only.
2. A and C only.
3. B and C only.
4. All

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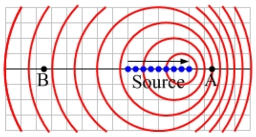
When the source moves, an observer being approached sees the wave fronts compressed, while an observed being moved away from sees the wave fronts dilated. The new frequency is the wave speed divided by the new wavelength.



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Standing waves

The two waves can be represented by the equations:
$y_1 = A \sin(kx - \omega t)$ and $y_2 = A \sin(kx + \omega t)$

The resultant wave is their sum, and can be written as:
$y = 2A \sin(kx) \cos(\omega t)$ Simulation

This is quite different from the equation of a traveling wave because the spatial part is separated from the time part. It tells us that there are certain positions where the amplitude is always zero - these points are called nodes. There are other points halfway between the nodes where the amplitude is maximum - these are the anti-nodes.

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Standing Waves

String fixed, or tube open at both ends: $f_n = \frac{nv}{2L}$, where n = 1, 2, 3, …

String fixed or tube closed at one end: $f_n = \frac{nv}{4L}$, where n = 1, 3, 5, …

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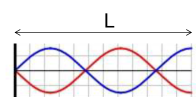
21. The figure at right shows the pattern of a standing wave on a string with one end fixed. What is the wavelength of this wave in terms of the length of the string, L?

1. L/3
2. 3L
3. 4L/5
4. 5L/4



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