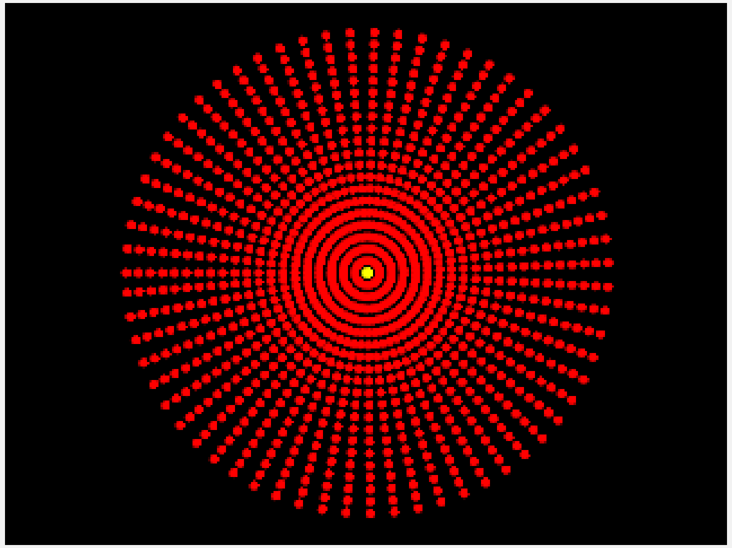
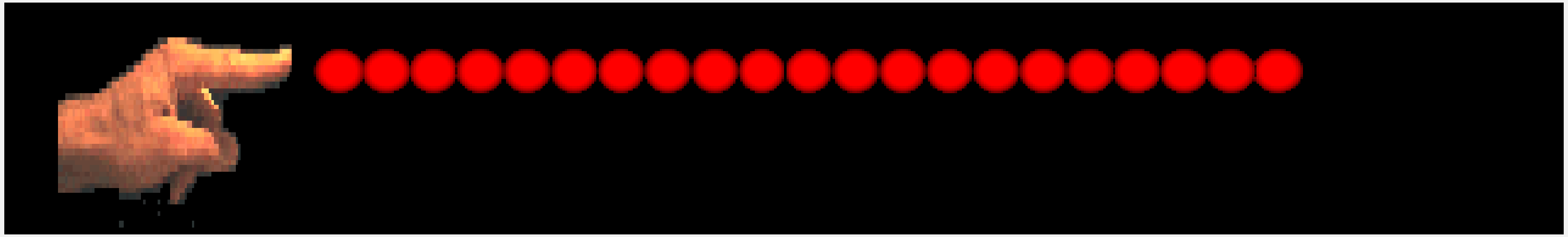
ONDE ELASTICHE

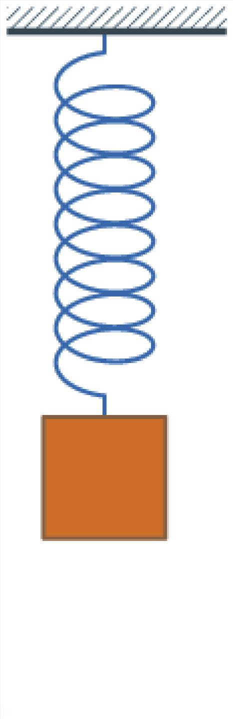
- Un'onda elastica è una perturbazione che si propaga in un mezzo elastico senza traslazione di materia

- Ogni punto del mezzo elastico oscilla intorno alla sua posizione di equilibrio con moto periodico





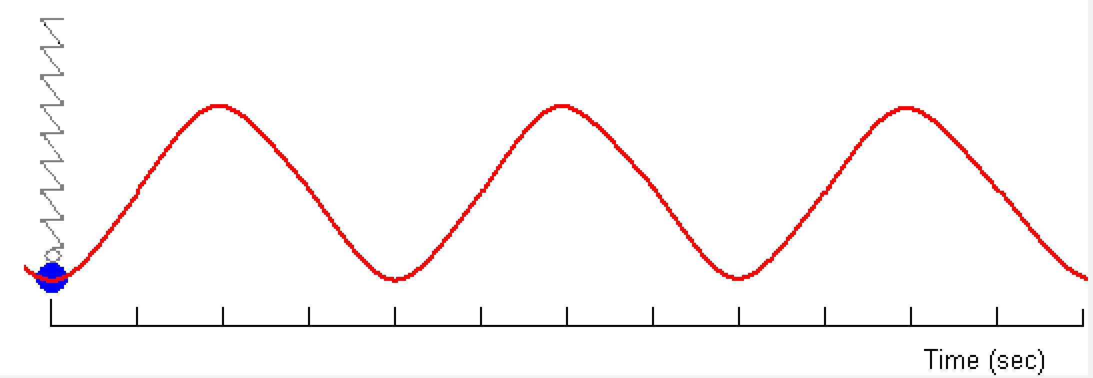
PROPERTIES OF PERIODIC MOTION



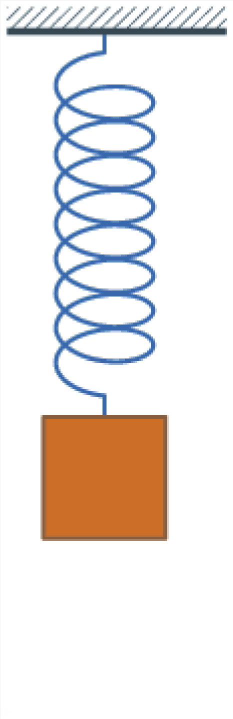
A vibrating object is wiggling about a fixed position: it moves over the same path over the course of time.
Without the damping, the vibrations would endure forever.

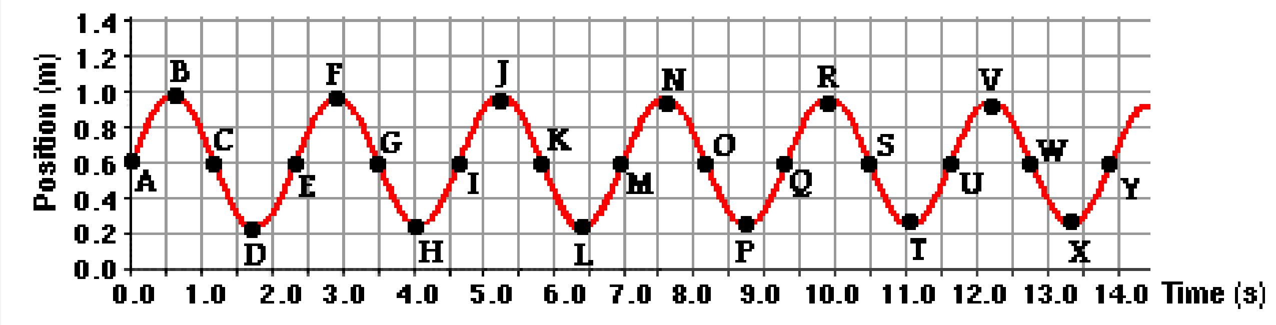
The mass on the spring repeats the same motion in a regular fashion.

In Physics, a motion that is regular and repeating is referred to as a **periodic motion**.



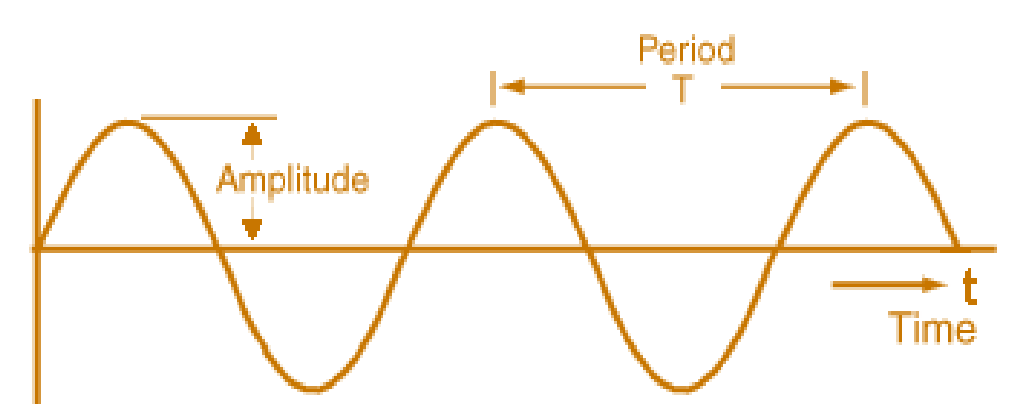
PROPERTIES OF PERIODIC MOTION

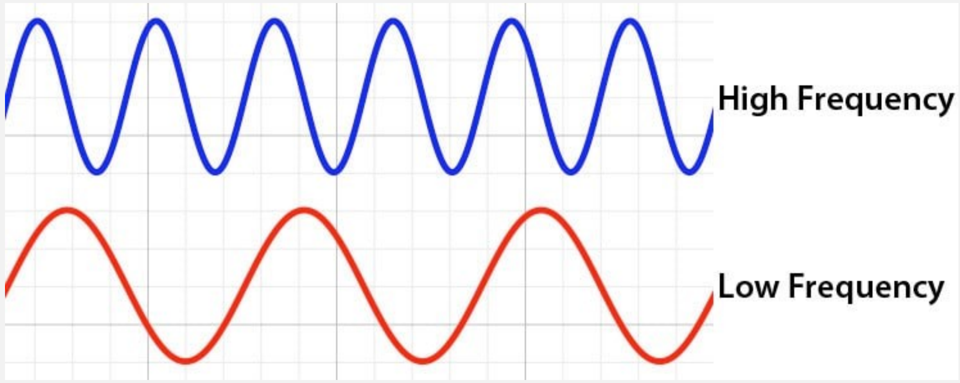




1. The shape of the graph: $y = sin(x)$
2. Periodic nature: the motion repeats itself in a regular fashion
3. Damping vibration

PERIOD AND FREQUENCY





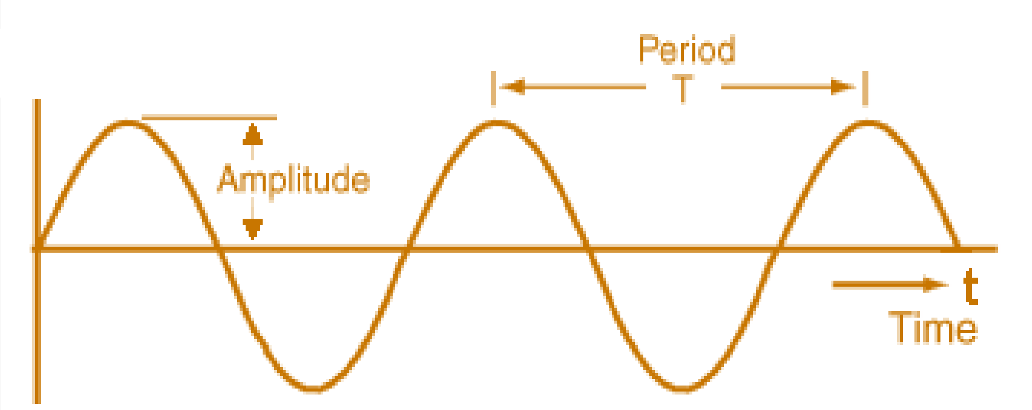
The period of the object's motion is defined as the time for the object to complete one full cycle. The standard metric unit for period is the second.

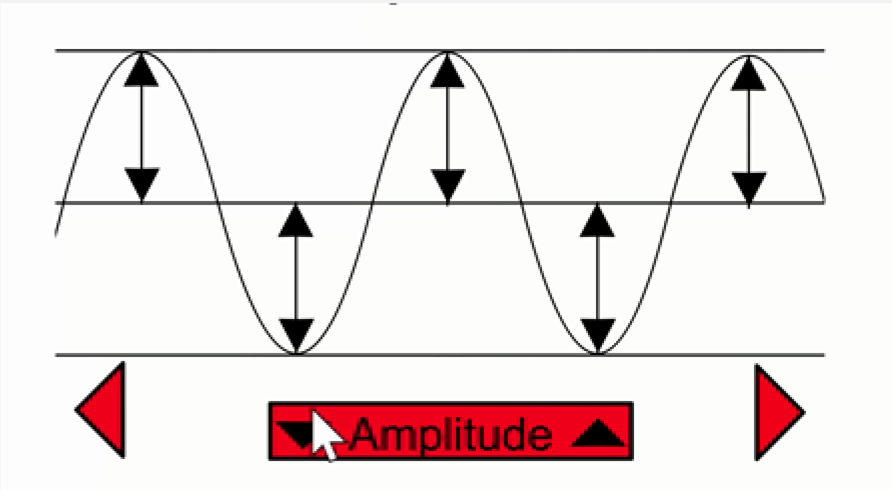
Frequency is defined as the number of complete cycles occurring per period of time. Frequency has units of cycles/second: Hertz, Hz.
Frequency and period are inversely related to each other: they are the reciprocal of each other.

$$period = \frac{1}{frequency}$$

$$frequency = \frac{1}{period}$$

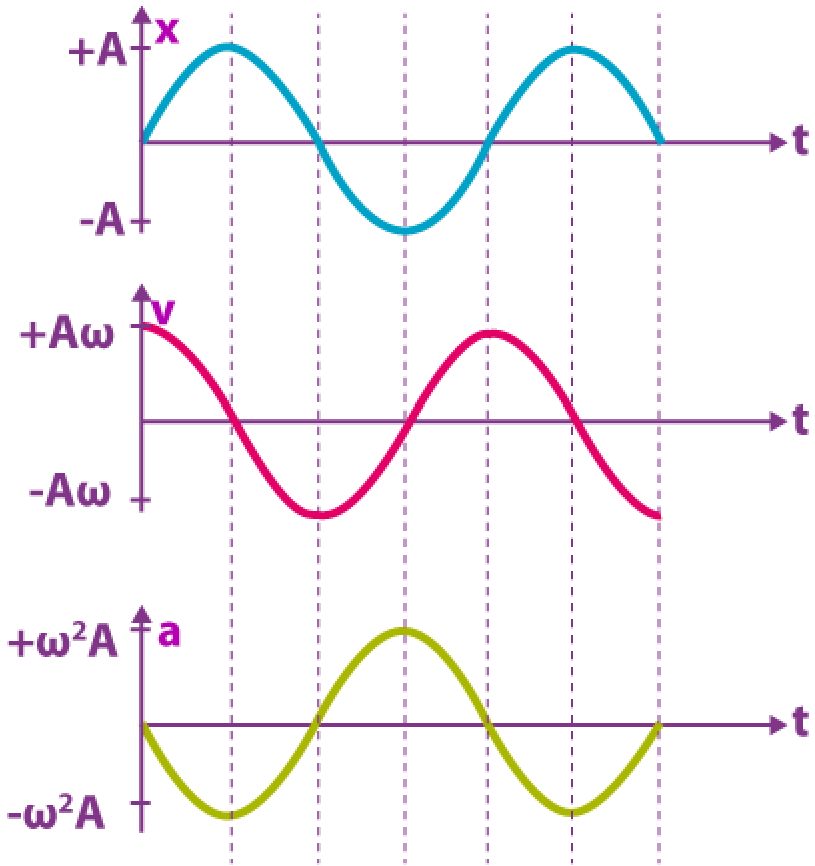
AMPLITUDE





Amplitude is defined as the maximum displacement of an object from its resting position.
The unit for amplitude is meter (m).

SUMMARY OF EQUATIONS



$$x(t) = A\cos(\omega t + \varphi)$$

$$\boldsymbol{x_{max} = A}$$

$$v(t) = -A\omega \sin(\omega t + \varphi) = -v_{max}\sin(\omega t + \varphi)$$

$$\boldsymbol{v_{max} = A\omega}$$

$$a(t) = -A\omega^2 \cos(\omega t + \varphi) = -a_{max}\cos(\omega t + \varphi)$$

$$\boldsymbol{a_{max} = A\omega^2}$$

ONDE

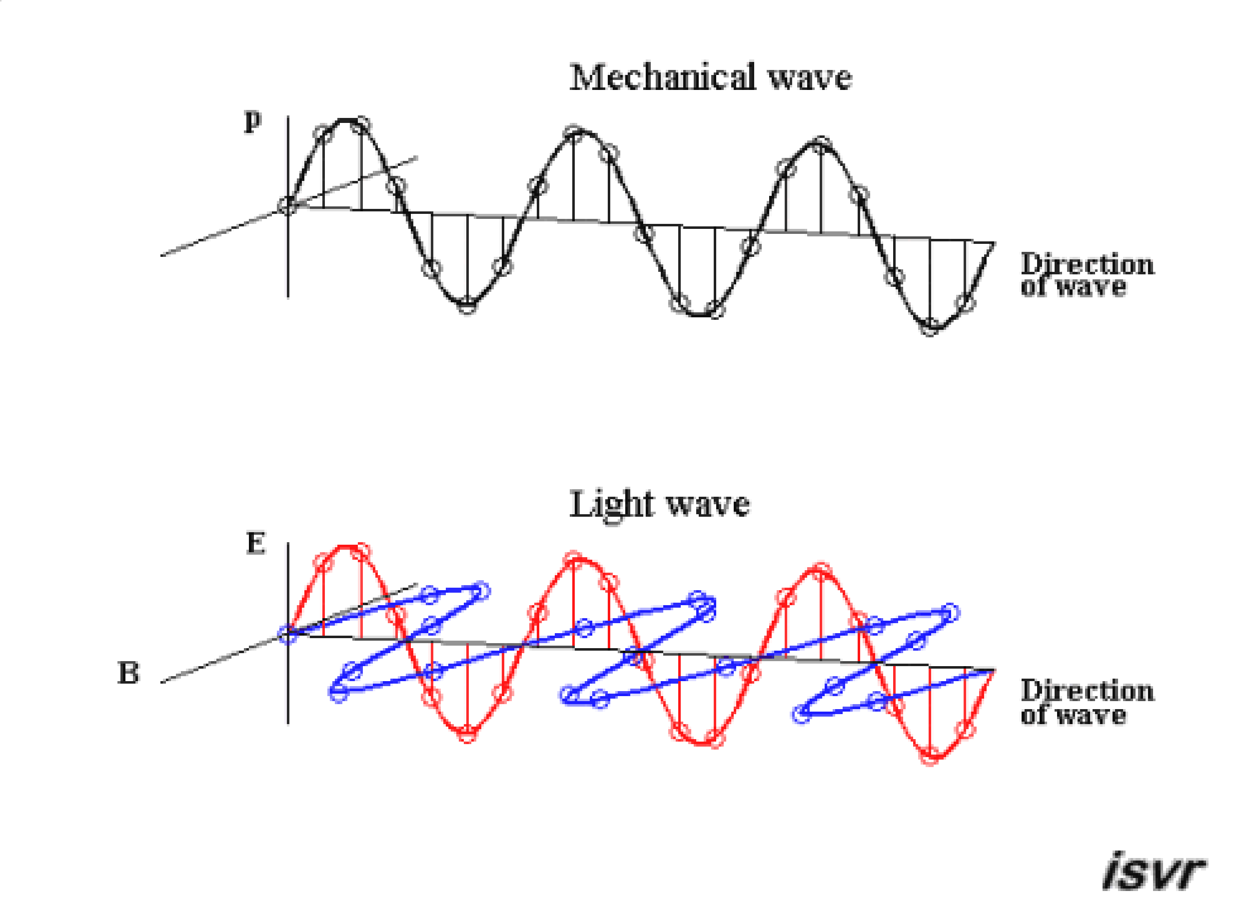
A wave is a disturbance that propagates, or moves from the place it was created.

There are three basic types of waves: mechanical waves, electromagnetic waves, and matter waves.

Basic **mechanical** waves are governed by Newton's laws and require a medium. The medium produces an elastic restoring force when it is deformed. Mechanical waves transfer energy and momentum, without transferring mass.

Electromagnetic waves are associated with oscillations in electric and magnetic fields and do not require a medium.

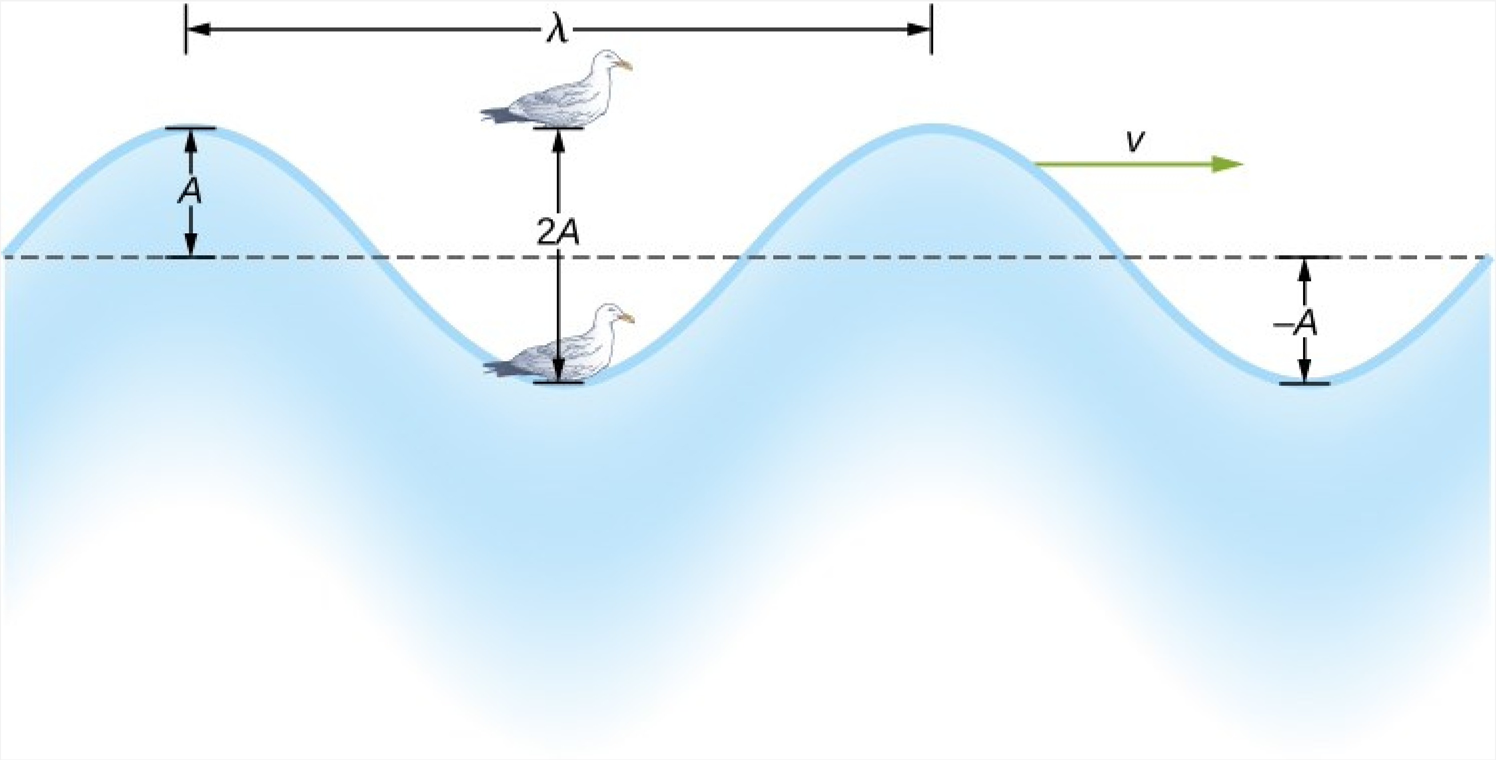
Matter waves are a central part of the branch of physics known as quantum mechanics. These waves are associated with protons, electrons, neutrons, and other fundamental particles found in nature.



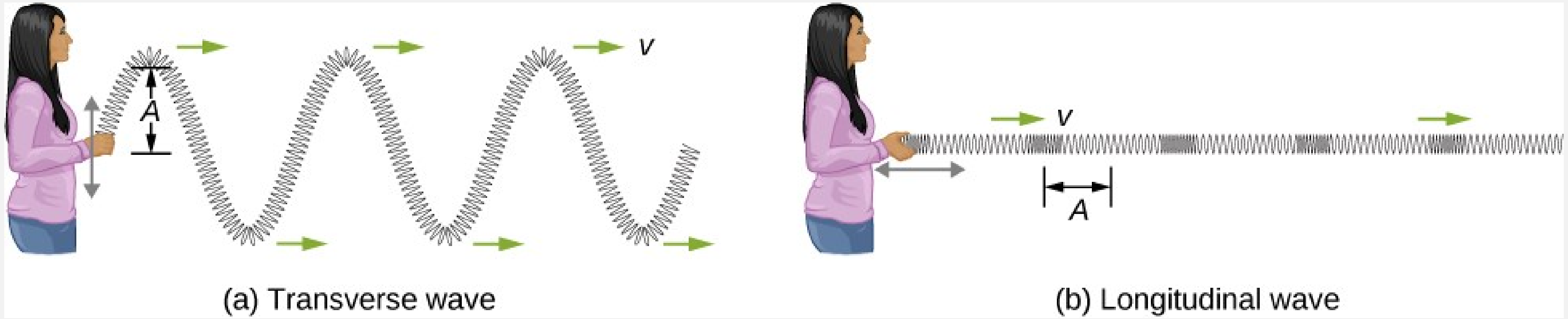
ONDE MECCANICHE

The simplest mechanical waves repeat themselves for several cycles and are associated with simple harmonic motion. These simple harmonic waves can be modeled using some combination of sine and cosine functions.

The magnitude of the wave velocity is the distance the wave travels in a given time, which is one wavelength in the time of one period, and the wave speed is the magnitude of wave velocity. In equation form, this is $v=\lambda/T=\lambda f$.

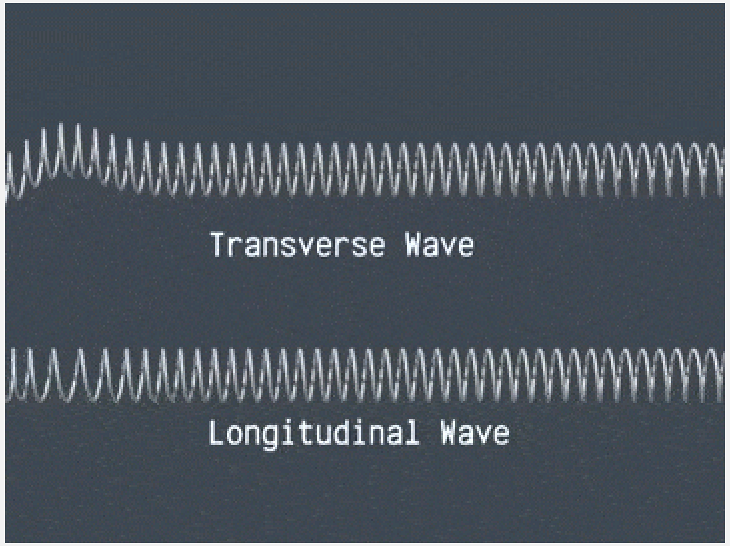


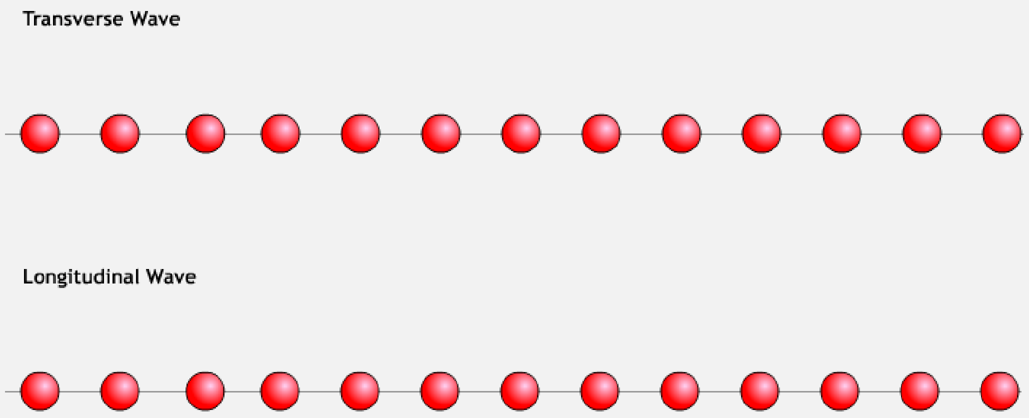
ONDE TRASVERSALI E LONGITUDINALI



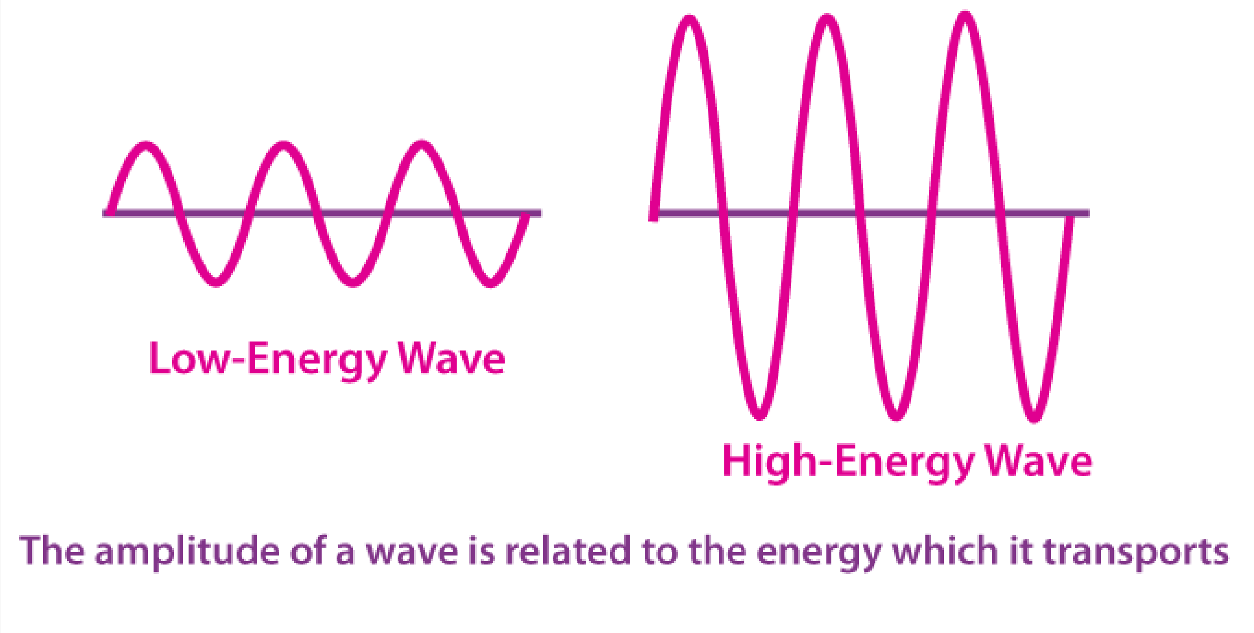
In a **transverse** wave, the wave may propagate in any direction, but the disturbance of the medium is perpendicular to the direction of propagation.

In a **longitudinal** wave, the disturbance is parallel to the direction of propagation. The size of the disturbance is its amplitude A and is completely independent of the speed of propagation v.





TRASPORTO DI ENERGIA E AMPIEZZA



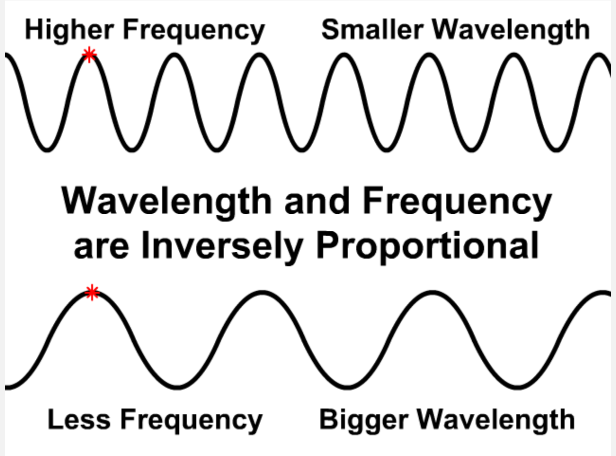
A high energy wave is characterized by a high amplitude; a low energy wave is characterized by a low amplitude.

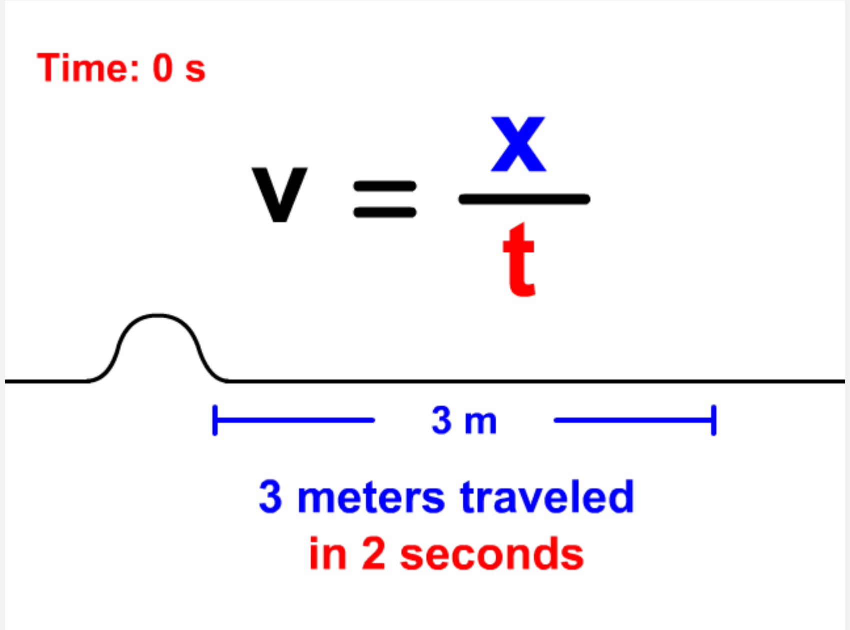
The amplitude of a wave refers to the maximum amount of displacement of a particle on the medium from its rest position.

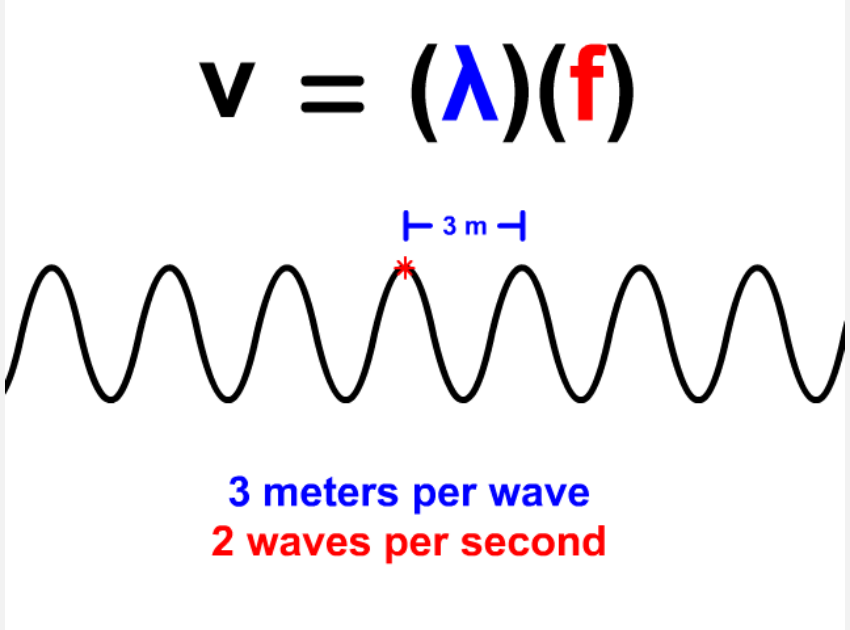
$$\boldsymbol{E \propto A^2}$$

EQUAZIONE DELLE ONDE

$$v = \lambda \cdot f \ \rightarrow v = \lambda / T$$





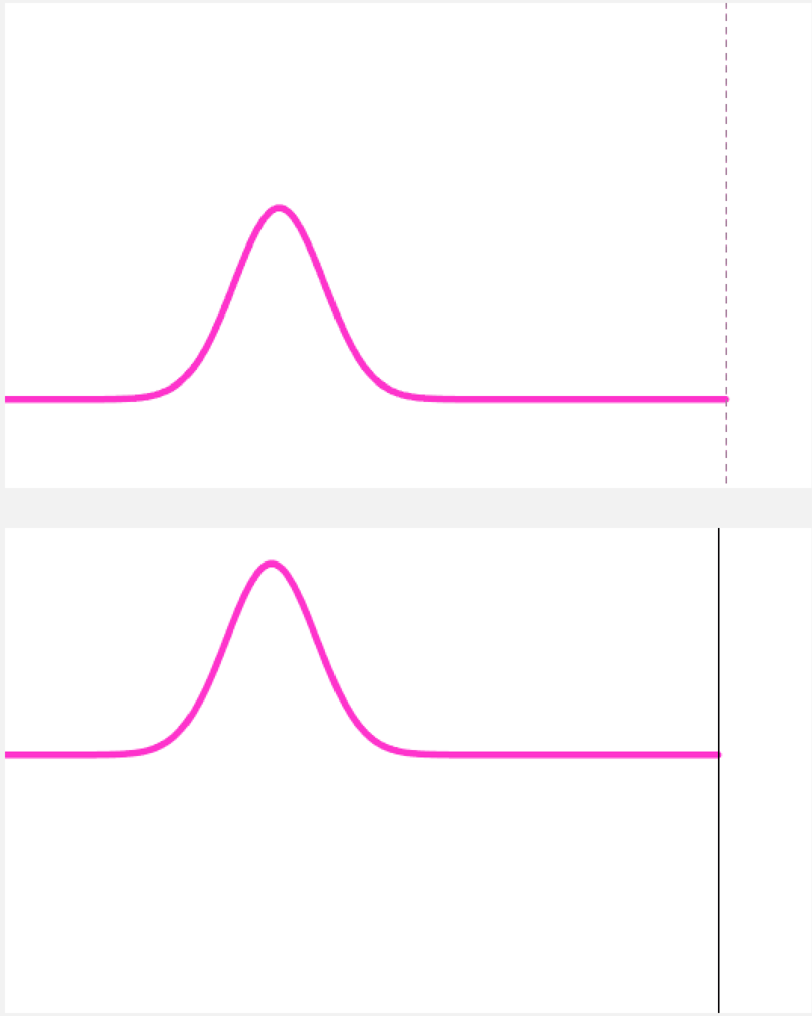


COMPORTAMENTO DELLE ONDE

BOUNDARY BEHAVIOUR

The behavior of a wave (or pulse) upon reaching the end of a medium is referred to as **boundary behavior**.

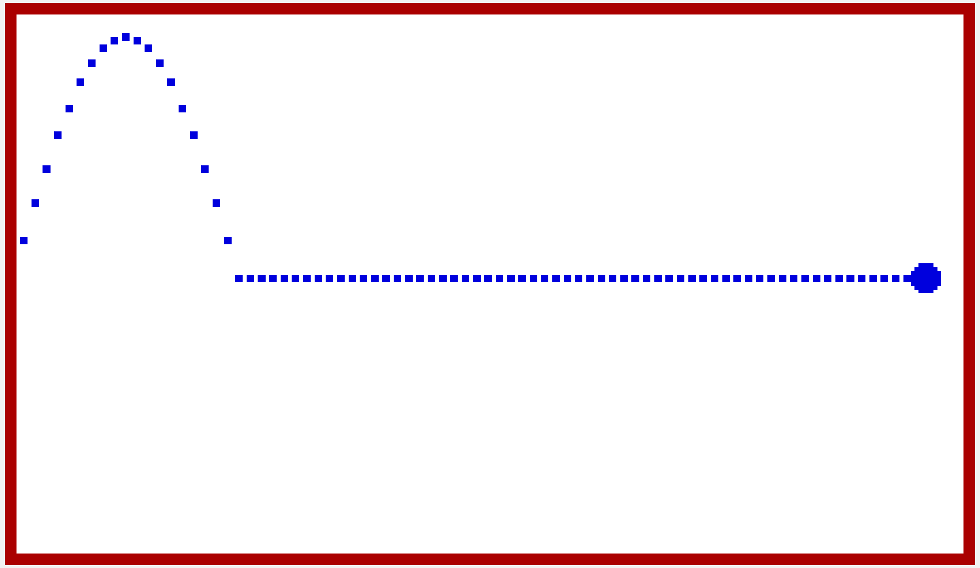
When one medium ends, another medium begins; the interface of the two media is referred to as the boundary and the behavior of a wave at that boundary is described as its boundary behavior.

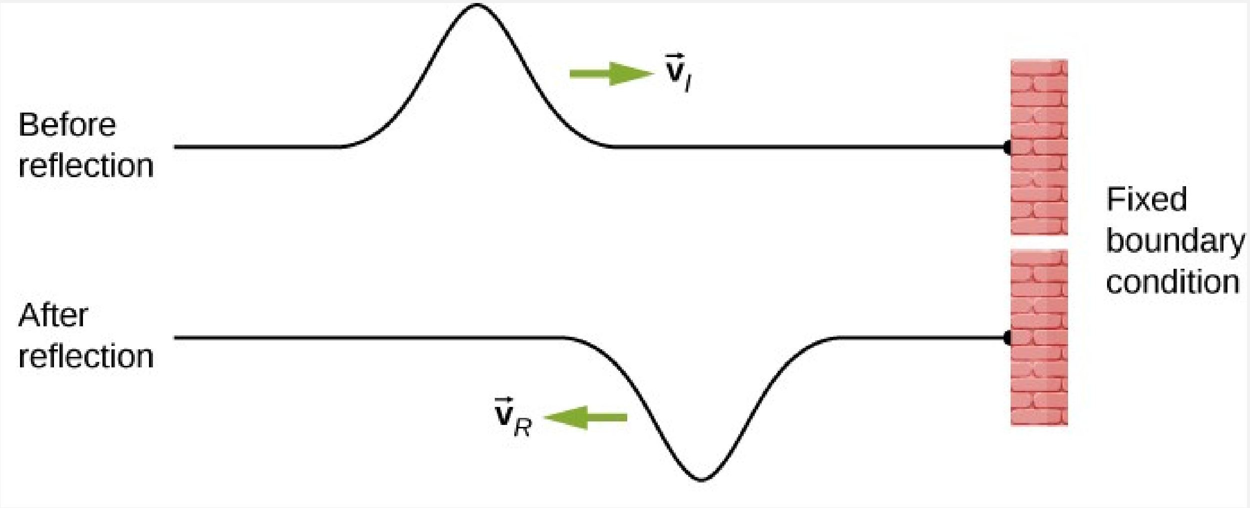


COMPORTAMENTO DELLE ONDE

FIXED END REFLECTION

If a pulse is introduced at the left end of the rope (FIXED), it will travel through the rope towards the right end of the medium.
When the incident pulse reaches the boundary, two things occur: (i) A portion of the energy carried by the pulse is reflected and returns towards the left end of the rope; (ii) A portion of the energy carried by the pulse is transmitted to the pole, causing the pole to vibrate.



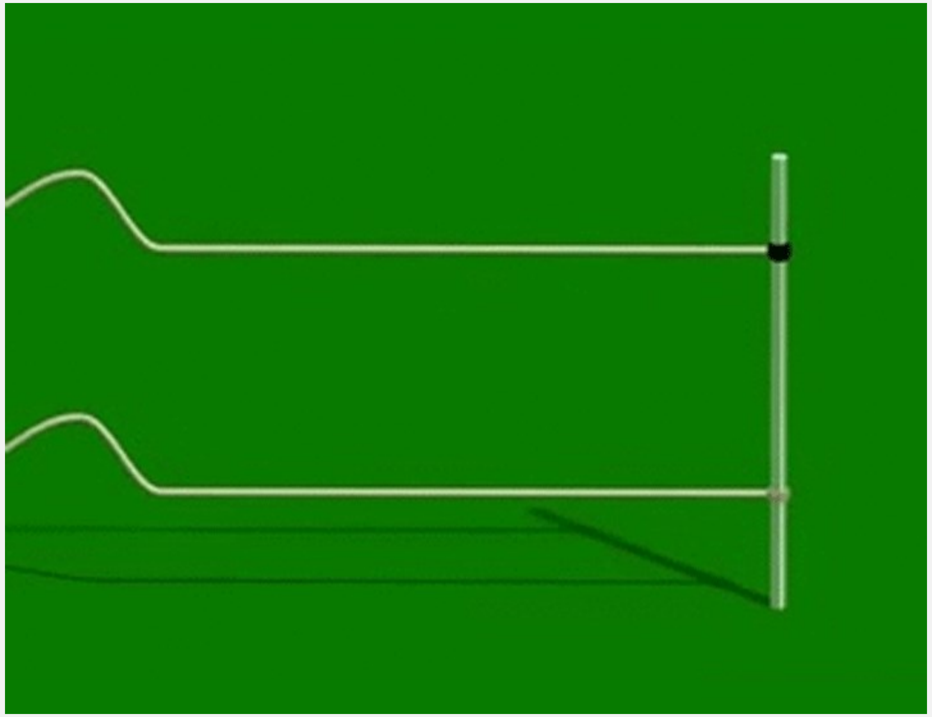


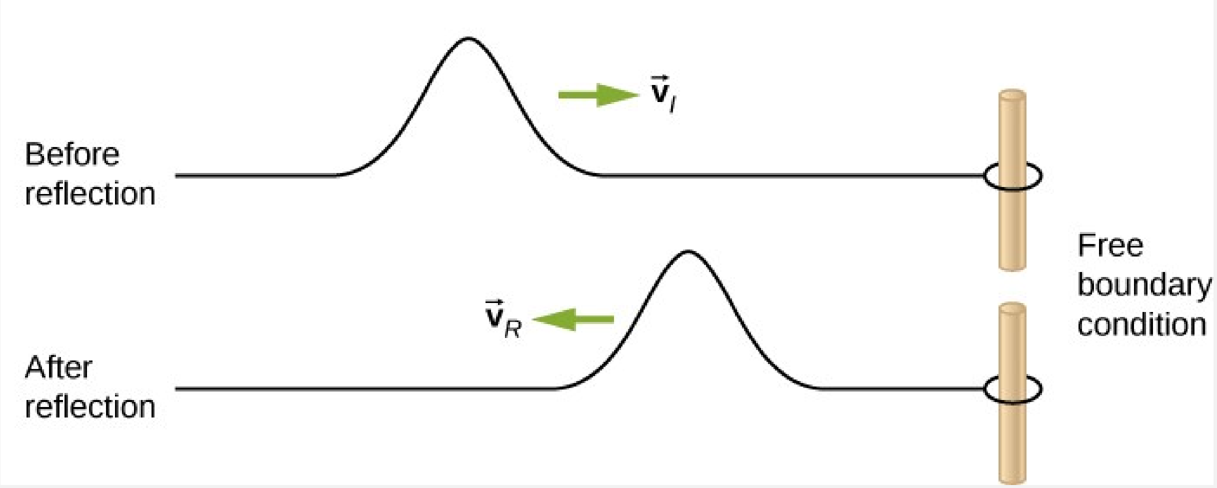
Pay attention to the reflected pulse:
- Inverted
- Same speed
- Same wavelength
- Minor amplitude

COMPORTAMENTO DELLE ONDE

FREE END REFLECTION

When a crest reaches the end of the rope, the last particle of the rope receives the same upward displacement.
The reflected pulse is not inverted. When an upward displaced pulse is incident upon a **free end**, it returns as an upward displaced pulse after reflection. And when a downward displaced pulse is incident upon a free end, it returns as a downward displaced pulse after reflection. Inversion is not observed in free end reflection.





Pay attention to the reflected pulse:

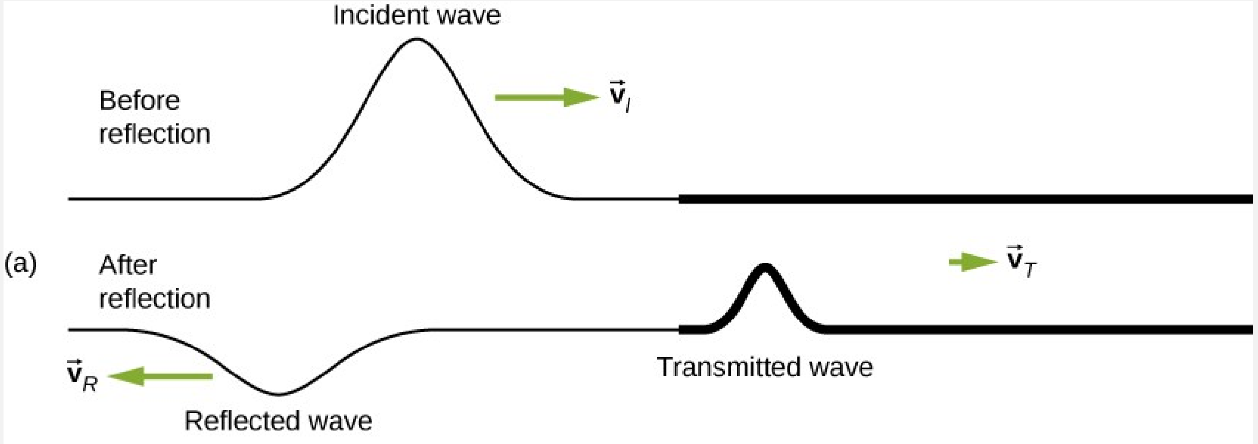
- Not inverted
- Same speed
- Same wavelength
- Minor amplitude

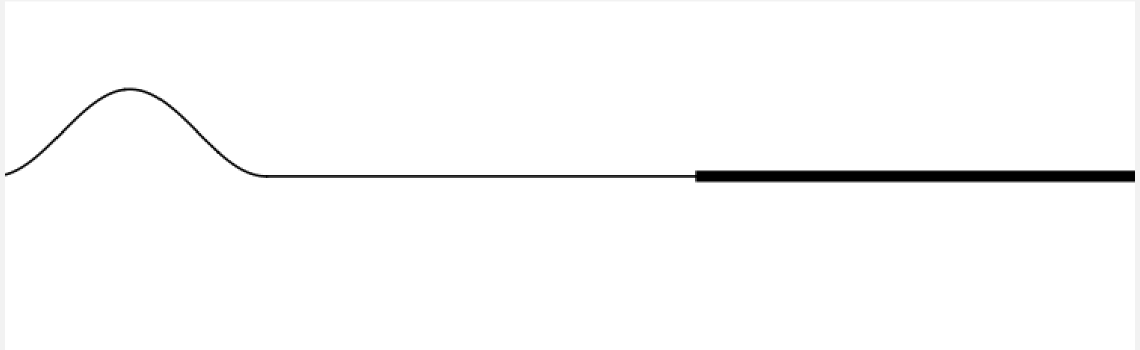

11
14

TRANSMISSION OF A PULSE ACROSS A BOUNDARY FROM LESS TO MORE DENSE

A portion of the energy carried by the incident pulse is reflected and returns towards the left end of the thin rope: reflected pulse (inverted!)

A portion of the energy carried by the incident pulse is transmitted into the thick rope: transmitted pulse (not inverted!)

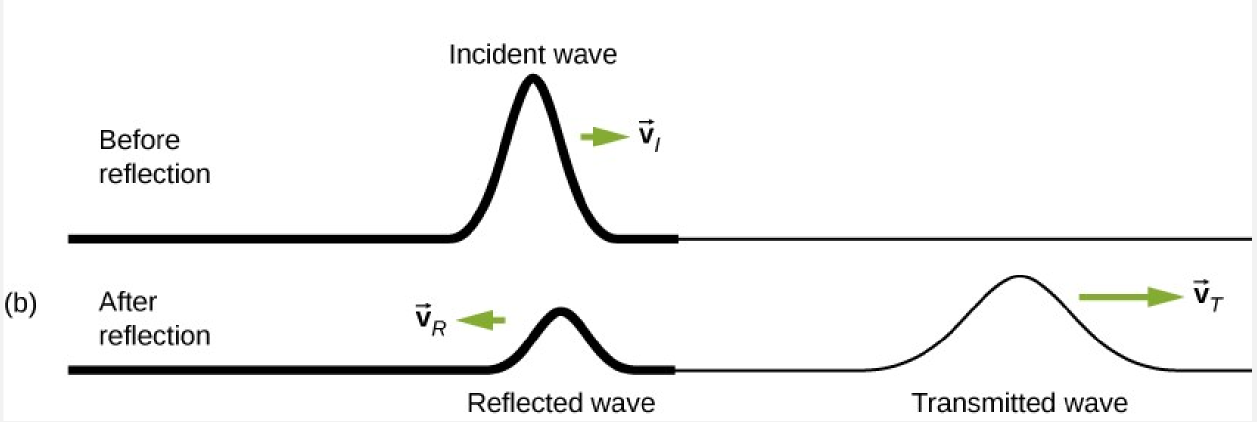


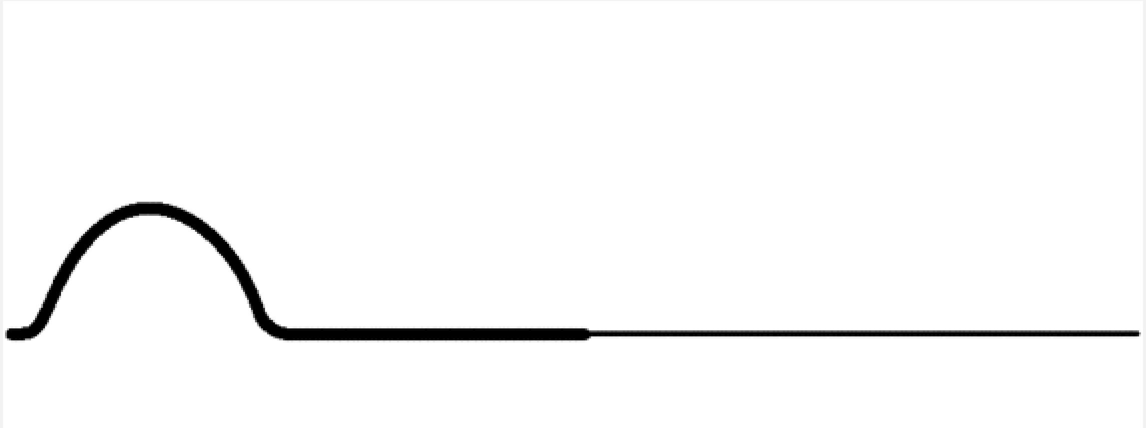


- The transmitted pulse is slower than the reflected pulse
- The transmitted pulse has a smaller wavelength than the reflected pulse
- The speed and the wavelength of the reflected pulse are the same as the speed and the wavelength of the incident pulse.

TRANSMISSION OF A PULSE ACROSS A BOUNDARY FROM MORE TO LESS DENSE

Once again there will be partial reflection and partial transmission at the boundary. The reflected pulse in this situation will not be inverted. Similarly, the transmitted pulse is not inverted (as is always the case).

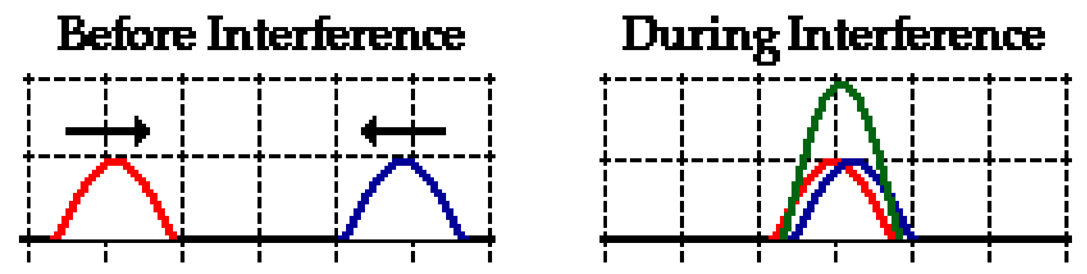


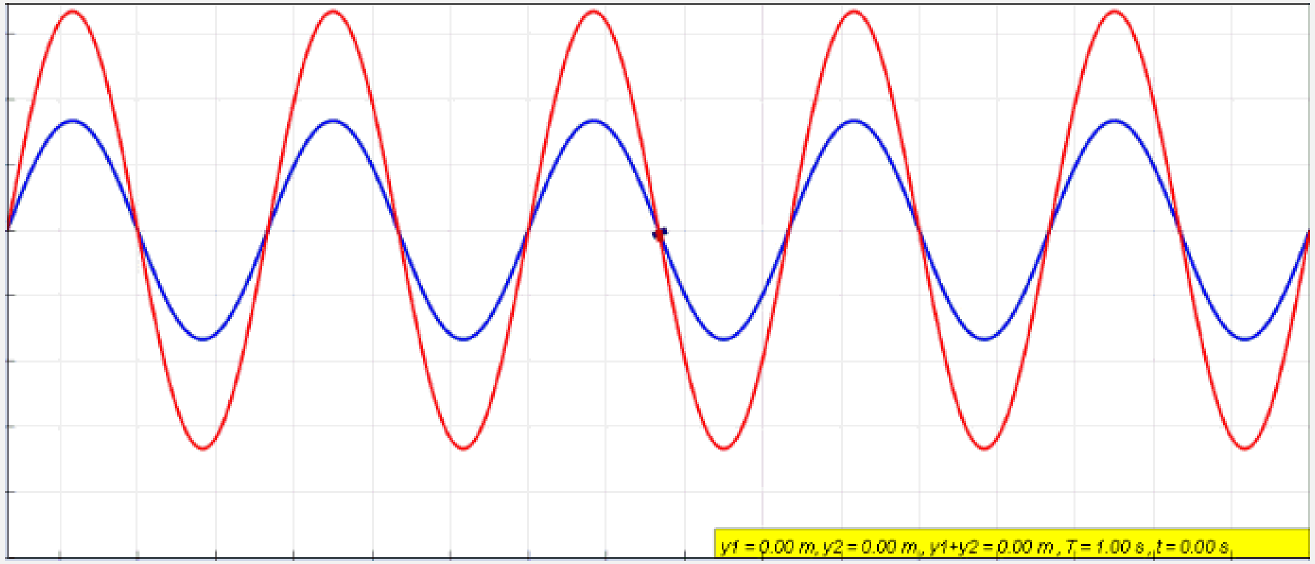


- The transmitted pulse is traveling faster than the reflected pulse.
- The transmitted pulse has a larger wavelength than the reflected pulse
- The speed and the wavelength of the reflected pulse are the same as the speed and the wavelength of the incident pulse.

INTERFERENCE OF WAVES

What happens when two waves meet while they travel through the same medium? What effect will the meeting of the waves have upon the appearance of the medium? Will the two waves bounce off each other upon meeting or will the two waves pass through each other?

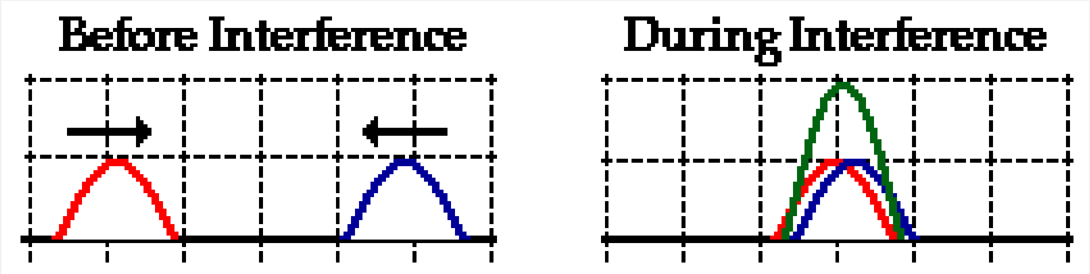


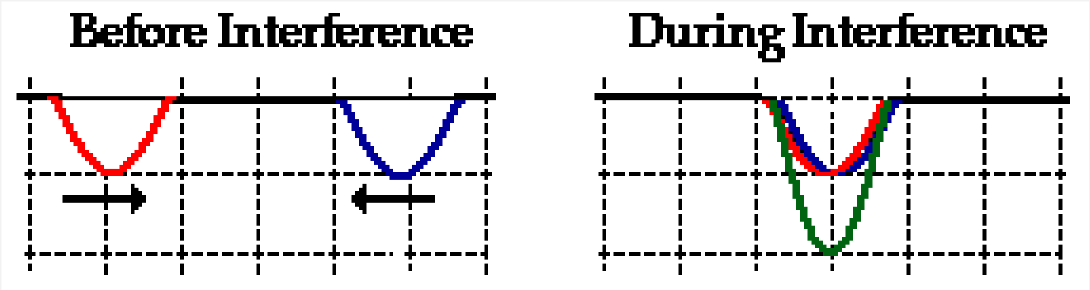


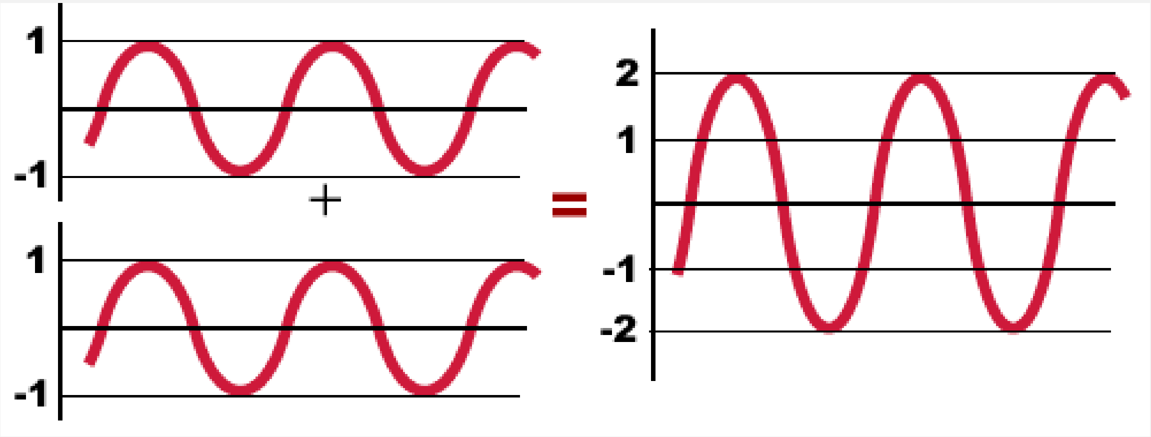
Wave interference is the phenomenon that occurs when two waves meet while traveling along the same medium.

CONSTRUCTIVE INTERFERENCE

Constructive interference is a type of interference that occurs at any location along the medium where **the two interfering waves have a displacement in the same direction.**

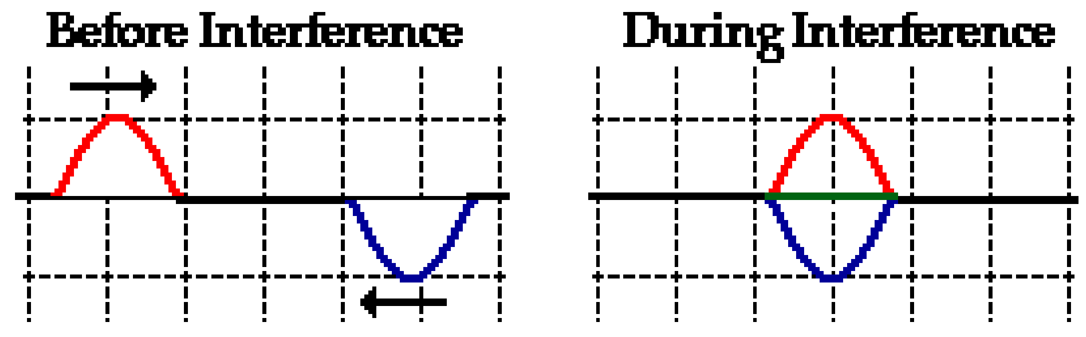


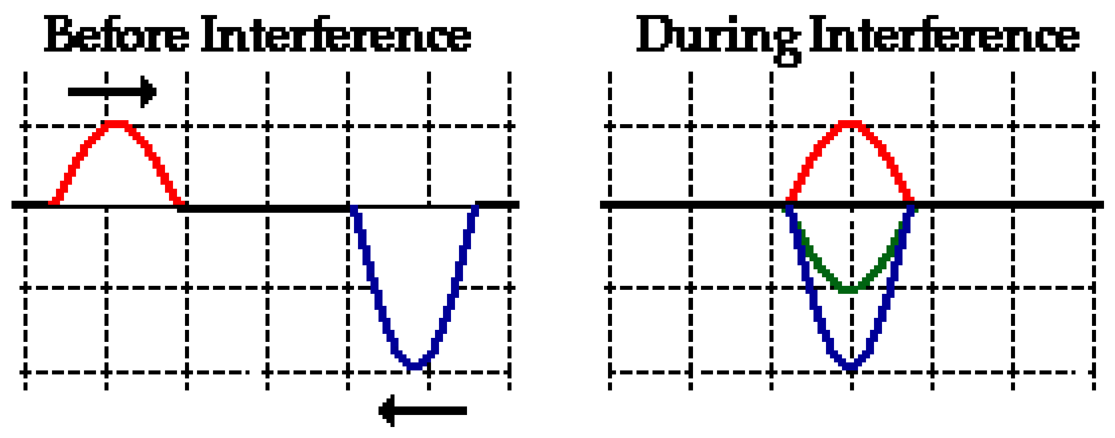


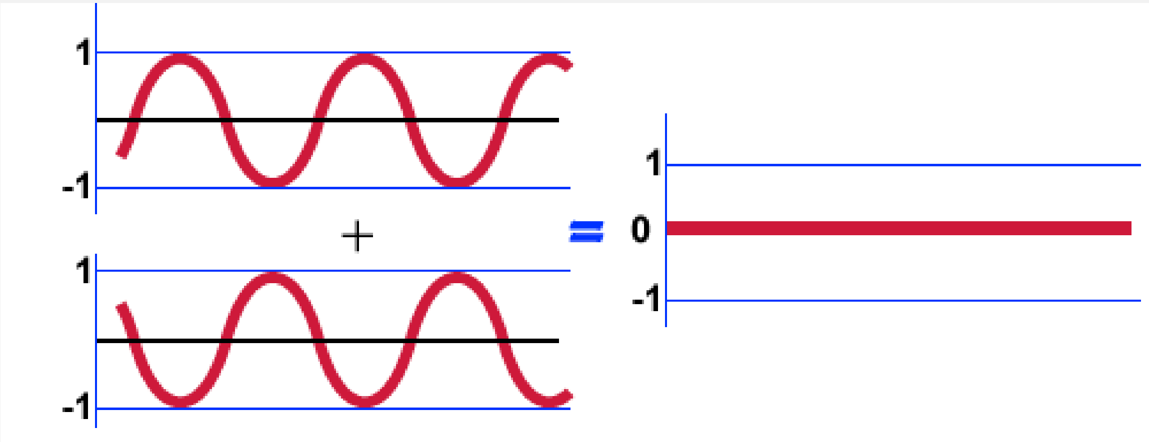


DESTRUCTIVE INTERFERENCE

Destructive interference is a type of interference that occurs at any location along the medium where **the two interfering waves have a displacement in the opposite direction.**



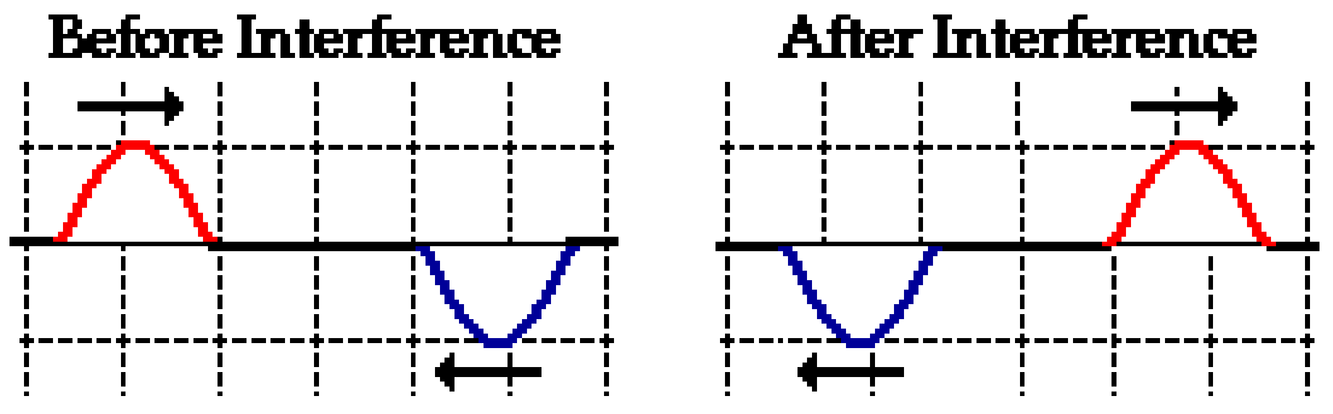




INTERFERENCE

Interestingly, the meeting of two waves along a medium does not alter the individual waves or even deviate them from their path.

Yet two waves will meet, produce a net resulting shape of the medium, and then **continue on doing what they were doing before the interference.**



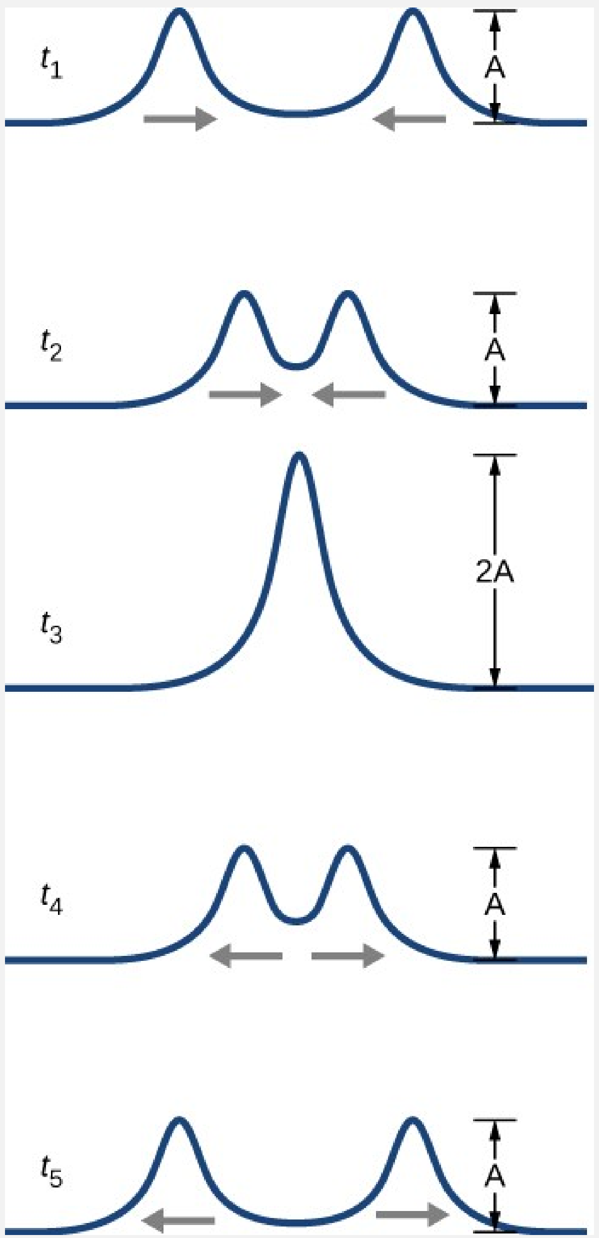
THE PRINCIPLE OF SUPERIMPOSITION

For mechanical waves, the principle of superposition states that if two or more traveling waves combine at the same point, the resulting position of the mass element of the medium, at that point, is the **algebraic sum of the position** due to the individual waves.

Mass on a spring→ $x(t) = A cos(\omega t + \varphi)$

Wave function modeling a sinusoidal wave → $\boldsymbol{y(x,t) = A sin(kx \mp \omega t + \varphi)}$

$(kx \mp \omega t + \varphi)$: phase of the wave



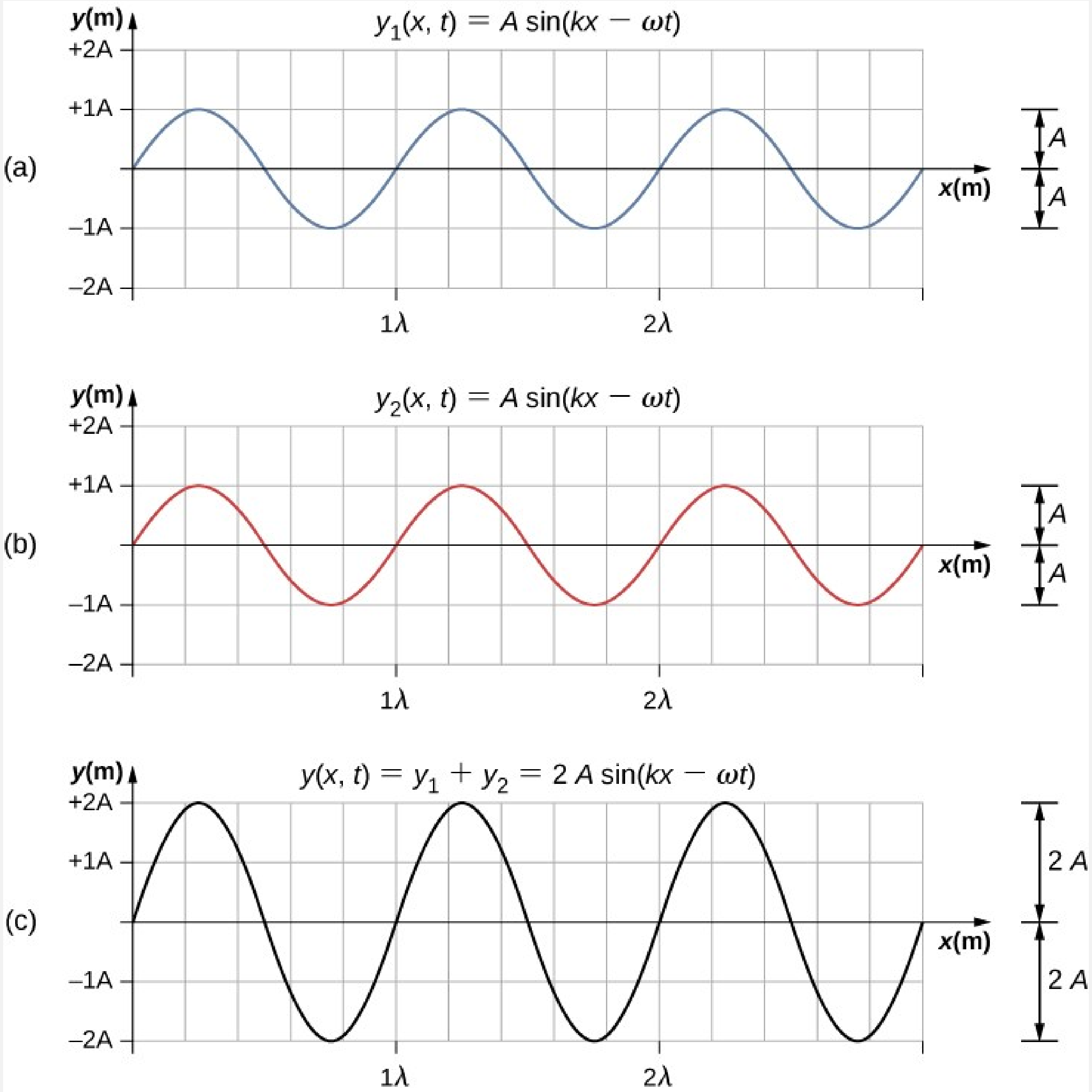
THE PRINCIPLE OF SUPERIMPOSITION

$$y(x,t) = A\sin(kx \mp \omega t + \varphi)$$

Two identical sinusoidal waves arrive at the same point exactly in phase.

The crests of the two waves are precisely aligned, as are the troughs.

This superposition produces constructive interference.
Because the disturbances add, constructive interference produces a wave that has twice the amplitude of the individual waves but has the same wavelength.

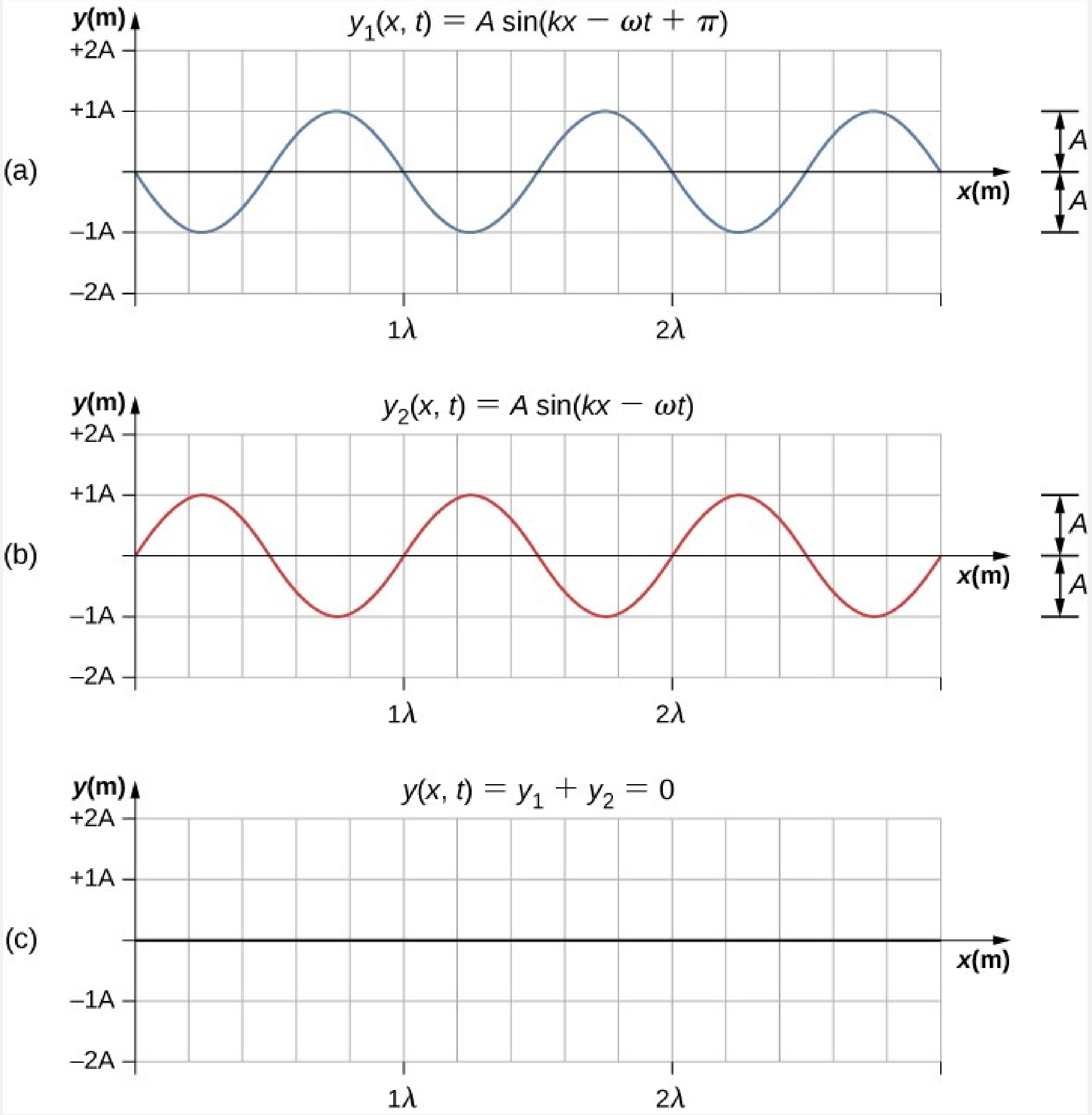


THE PRINCIPLE OF SUPERIMPOSITION

$$y(x,t) = Asin(kx \mp \omega t + \varphi)$$

Two identical sinusoidal waves arrive exactly 180° out of phase, producing destructive interference.

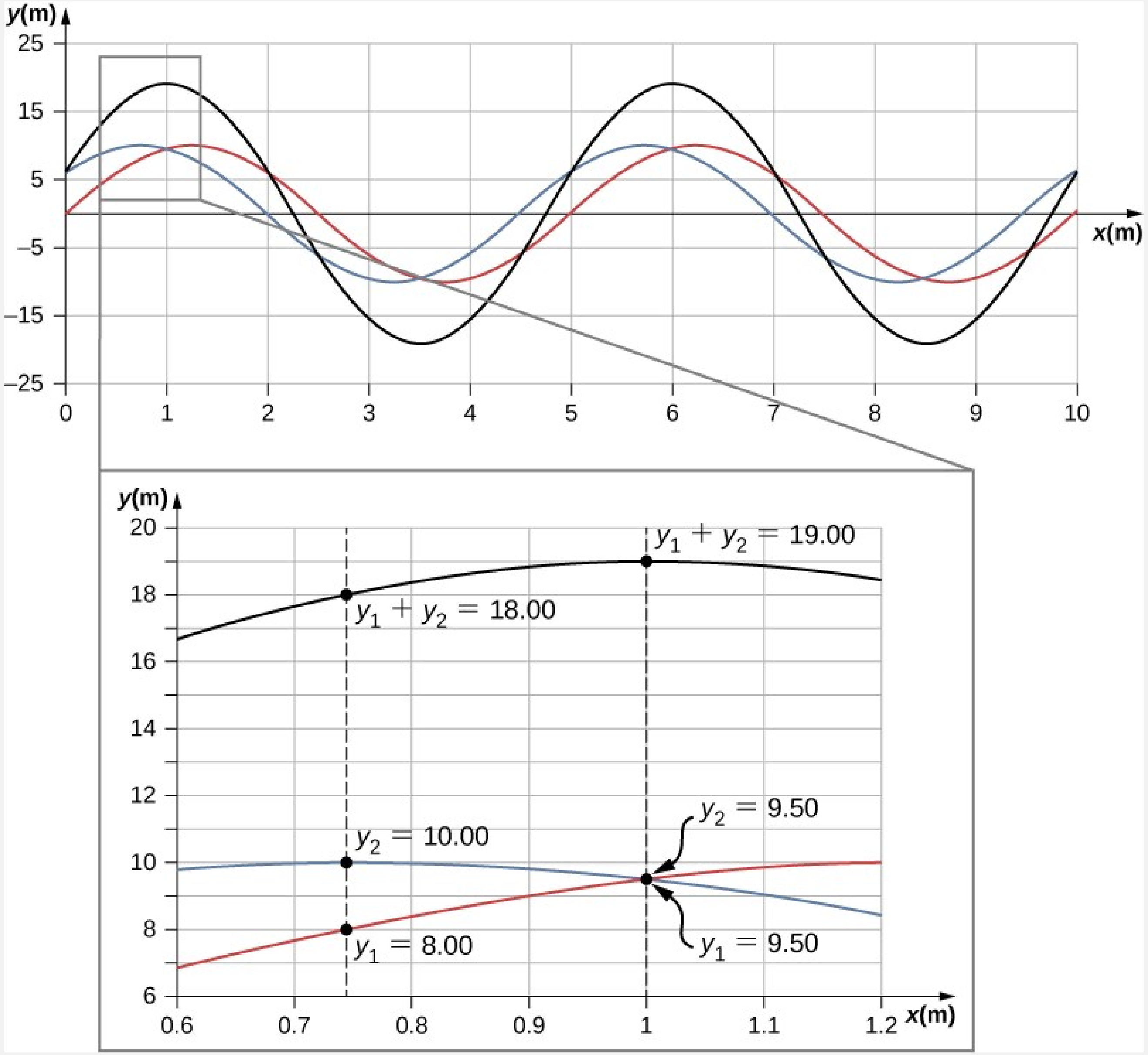
Because the troughs of one wave add the crest of the other wave, the resulting amplitude is zero for destructive interference—the waves completely cancel.



THE PRINCIPLE OF SUPERIMPOSITION

$$y(x,t) = A\sin(kx \mp \omega t + \varphi)$$

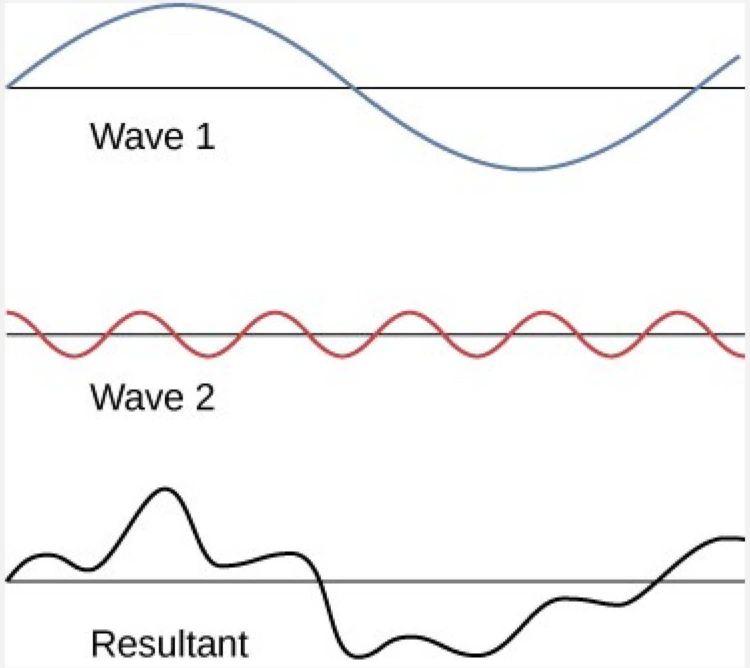
When linear waves interfere, the resultant wave is just the algebraic sum of the individual waves as stated in the principle of superposition.



THE PRINCIPLE OF SUPERIMPOSITION

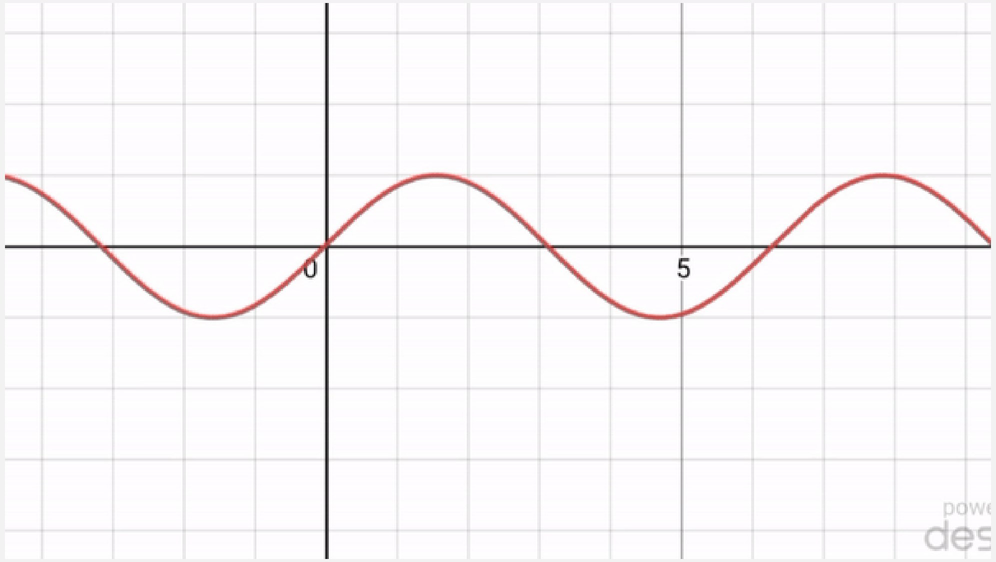
The superposition of most waves produces a **combination of constructive and destructive interference**.

The superposition of two dissimilar waves can produce a pattern that is rich in complexity, some without any readily discernable patterns.

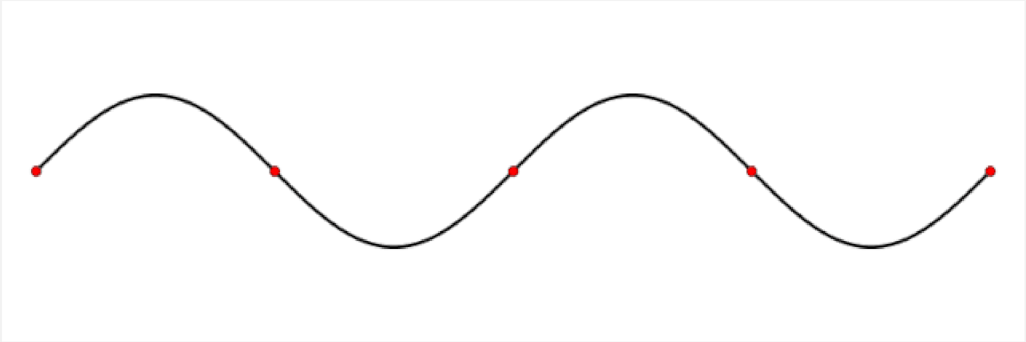


TRAVELLING WAVES vs. STANDING WAVES

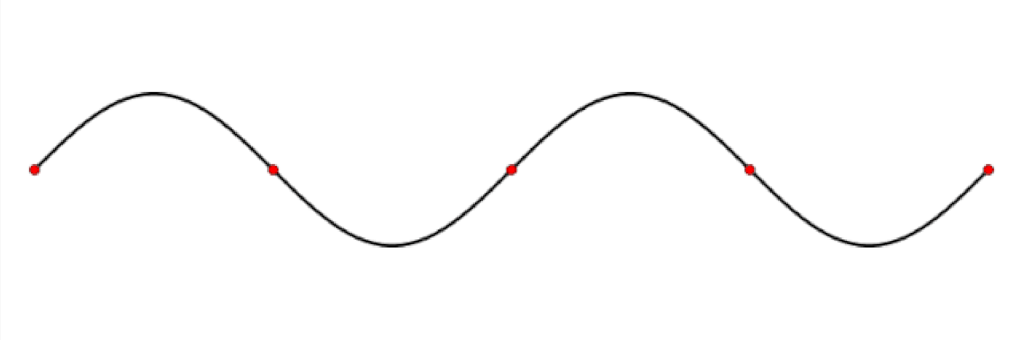
Traveling waves are observed when a wave is not confined to a given space along the medium.



A standing wave is confined to a given space in a medium and still produces a regular wave pattern.

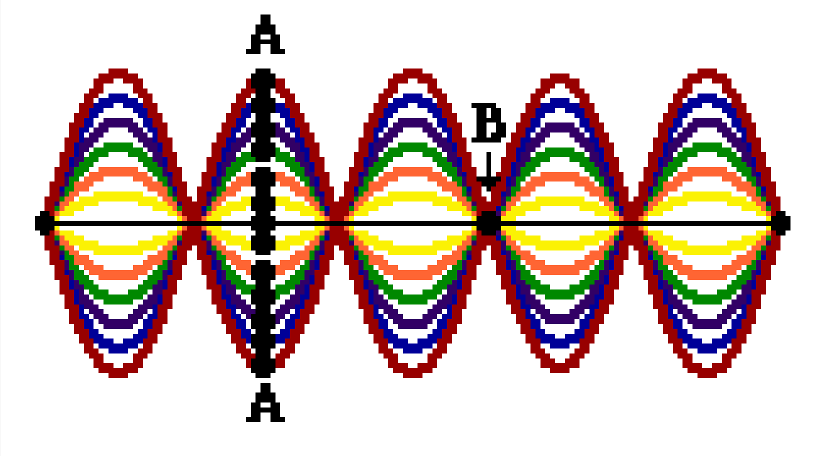


TRAVELLING WAVES vs. STANDING WAVES



Point A moves from a maximum positive to a maximum negative displacement over time. The motion would continue and persist, with point A returning to the same maximum positive displacement and then continuing its back-and-forth vibration between the up to the down position.

Point B is a point that never moves. Point B is a point of no displacement. Such points are known as **nodes**.

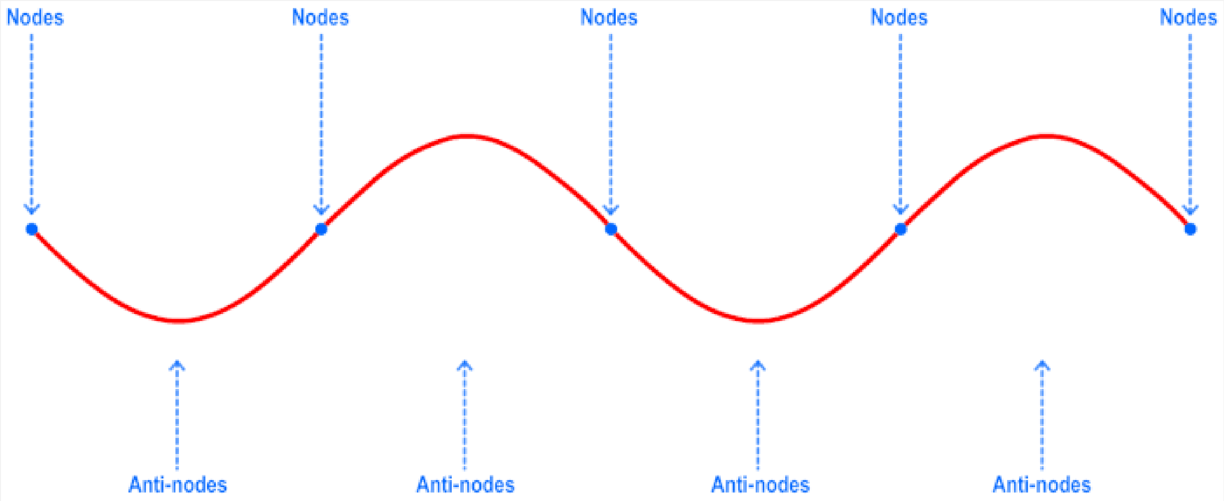


NODES AND ANTI-NODES

A standing wave pattern always consists of an alternating pattern of nodes and antinodes.

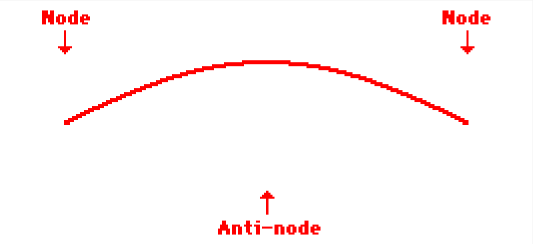
There are points that appear to be standing still: points of no displacement, **nodes**.

There are other points that undergo vibrations between a large positive and large negative displacement: points of maximum displacement, **antinodes**.

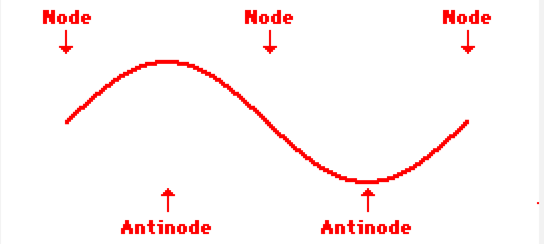


HARMONICS AND PATTERNS

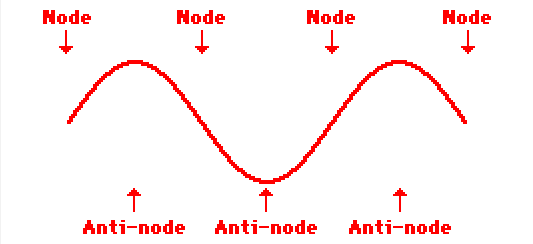
A variety of wave patterns could be produced, with each pattern characterized by a distinctly different number of nodes.



First harmonic standing wave pattern. The simplest standing wave pattern has points of no displacement (nodes) at the two ends and one point of maximum displacement (antinode) in the middle.



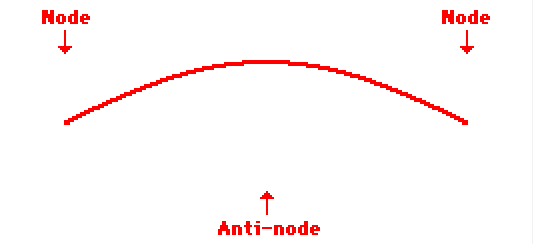
Second harmonic standing wave pattern. Three nodes and two anti-nodes. It occurs when the vibrations has greater frequency.

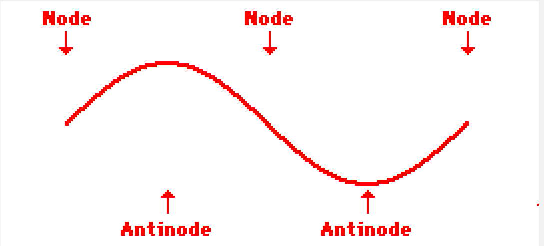


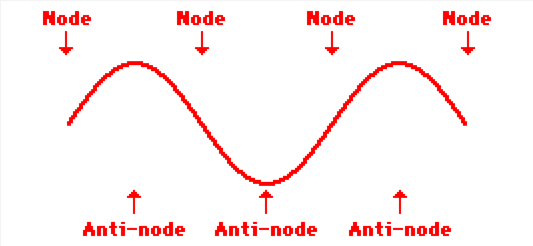
Third harmonic standing wave pattern. An additional node and an additional anti-node.

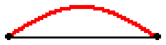
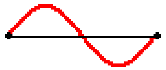
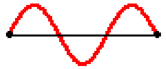
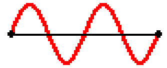
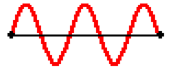
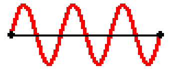
HARMONICS AND PATTERNS

Numerical patterns associated with standing wave diagrams.







Harmonic	# of Nodes	# of Antinodes	Pattern
1st	2	1	
2nd	3	2	
3rd	4	3	
4th	5	4	
5th	6	5	
6th	7	6	
nth	n + 1	n	--

Grandezze fondamentali per la descrizione dell'onda:

- *velocità di propagazione* c (o *velocità di fase*), che dipende dal mezzo in cui l'onda si propaga

- *periodo* T : tempo che intercorre tra il passaggio di due fronti d'onda successivi in uno stesso punto

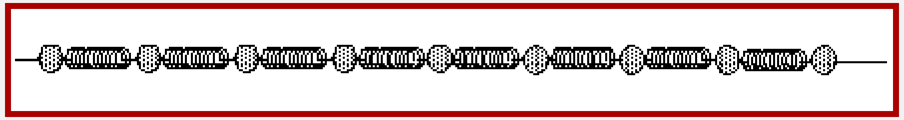
- *frequenza* ν $(=1/T)$: numero di fronti d'onda che attraversano un dato punto nell'unità di tempo; si misura in Hertz ($1\ Hz = 1\ s^{-1}$)

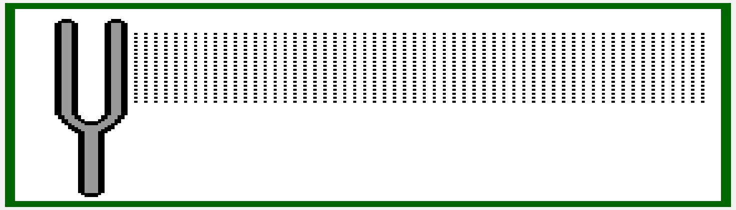
- *lunghezza d'onda* λ : distanza spaziale tra due fronti d'onda successivi

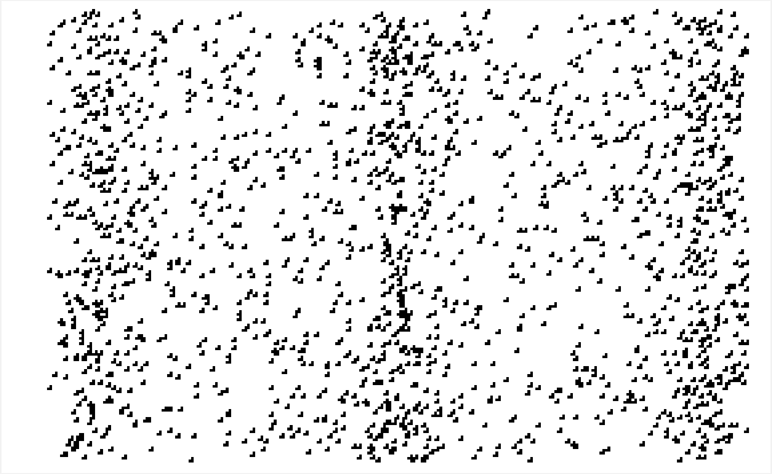
Tra queste grandezze esistono le relazioni fondamentali:

$\lambda = cT$ ovvero $\lambda = c\ /\ \nu$

SOUND WAVES ARE MECHANICAL WAVES

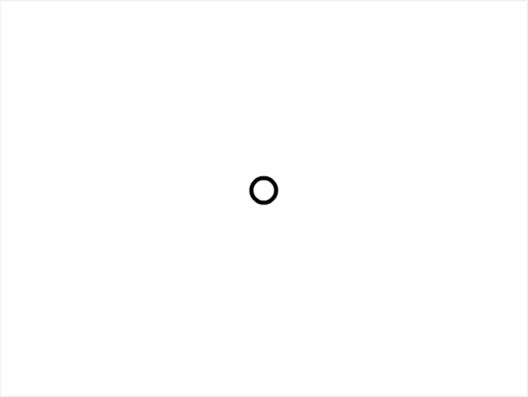




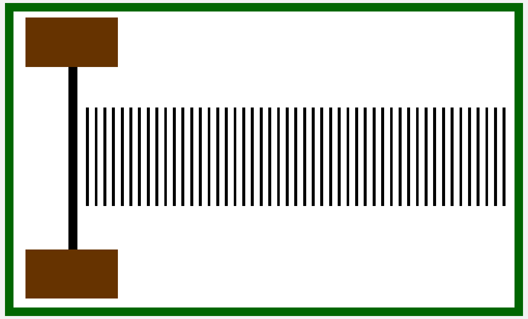


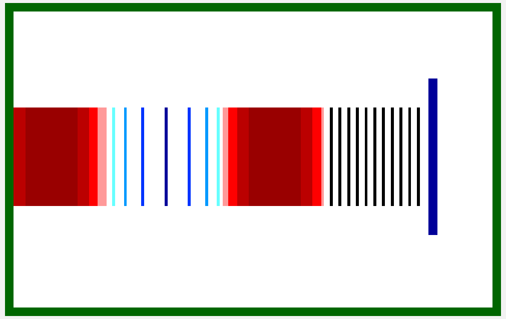
Sound is a wave that is created by vibrating objects and propagated through a medium from one location to another.

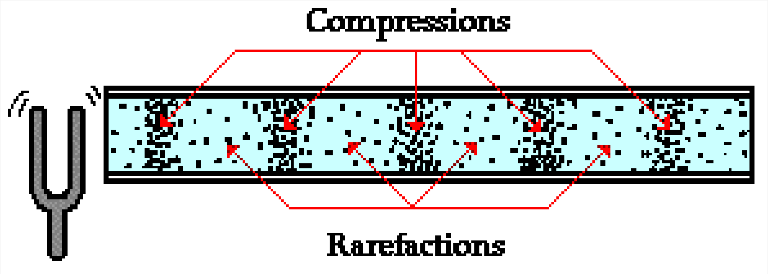
For a sound wave traveling through air, the vibrations of the particles are best described as longitudinal. Longitudinal waves are waves in which the motion of the individual particles of the medium is in a direction that is parallel to the direction of energy transport.



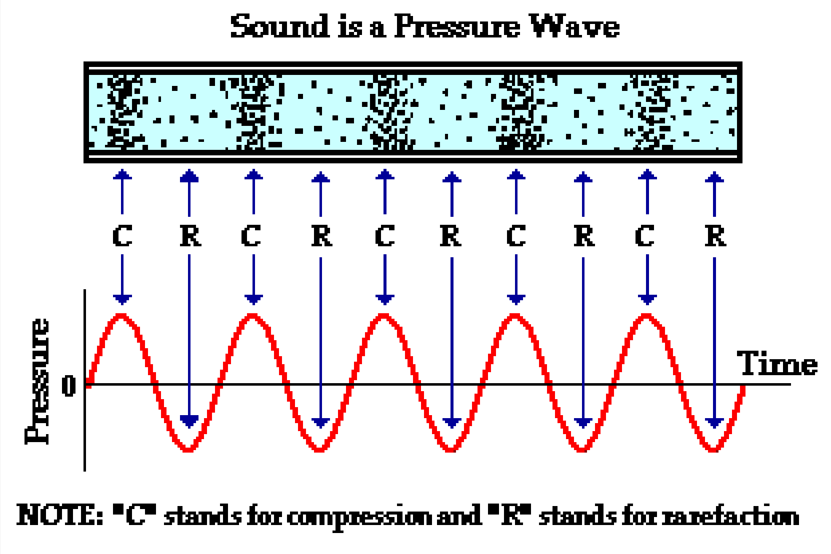
The result of such longitudinal vibrations is the creation of compressions and rarefactions within the air (PRESSURE WAVE).
The compressions are regions of high air pressure while the rarefactions are regions of low air pressure.



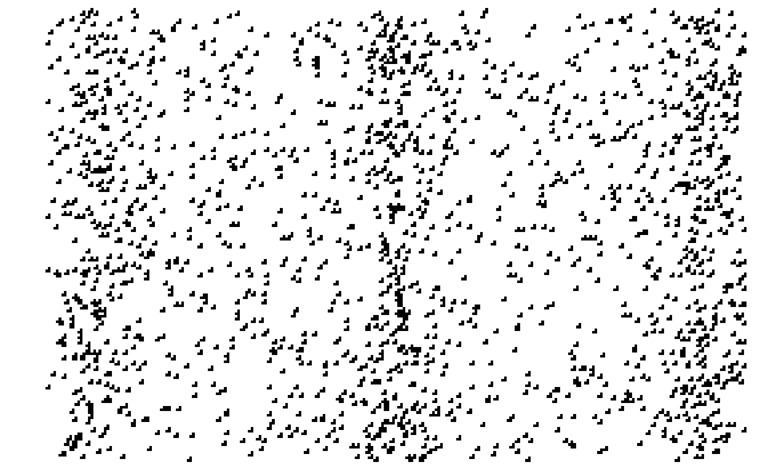




The fluctuations in pressure as detected by the detector occur at periodic and regular time intervals (sine function).
The peak points of the sine curve correspond to compressions; the low points correspond to rarefactions; and the "zero points" correspond to the pressure that the air would have if there were no disturbance moving through it.



Onda sonora



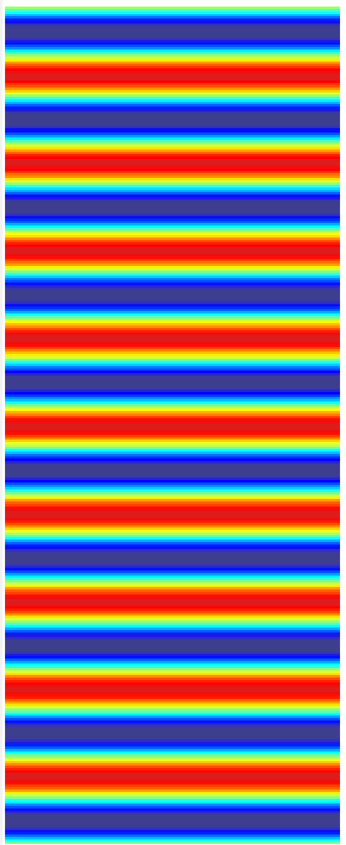
Un'onda sonora è udibile dall'orecchio umano se la sua frequenza è compresa nell'intervallo

20 Hz – 20000 Hz

Infrasuoni = suoni caratterizzati da una frequenza inferiore a 20 Hz (non percepibili dall'orecchio umano)

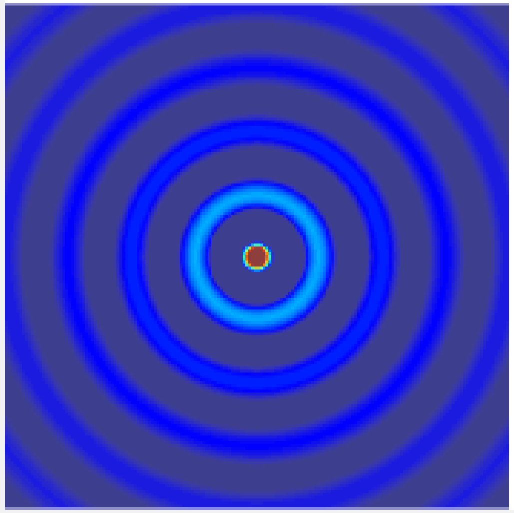
Ultrasuoni = suoni caratterizzati da una frequenza superiore a 20 kHz (non percepibili dall'orecchio umano)

Infrasuoni, suoni e ultrasuoni sono caratterizzati dalle stesse proprietà



- Il FRONTE d’ONDA è il luogo dei punti interessati dalla perturbazione nel medesimo istante

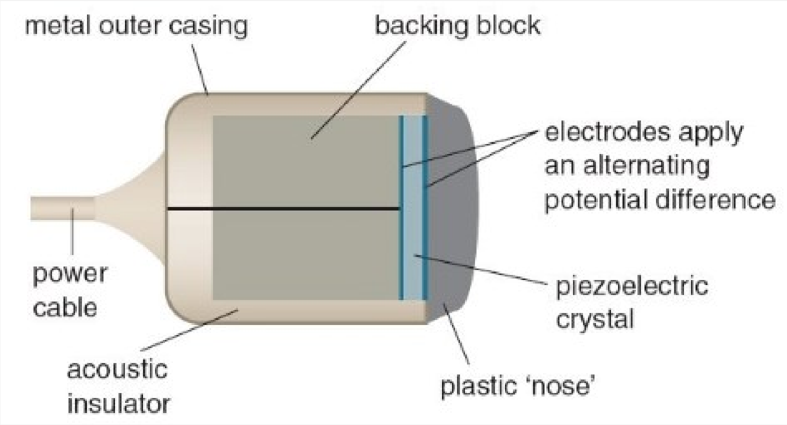
- Se i fronti d’onda sono dei piani paralleli si parla di ONDA PIANA

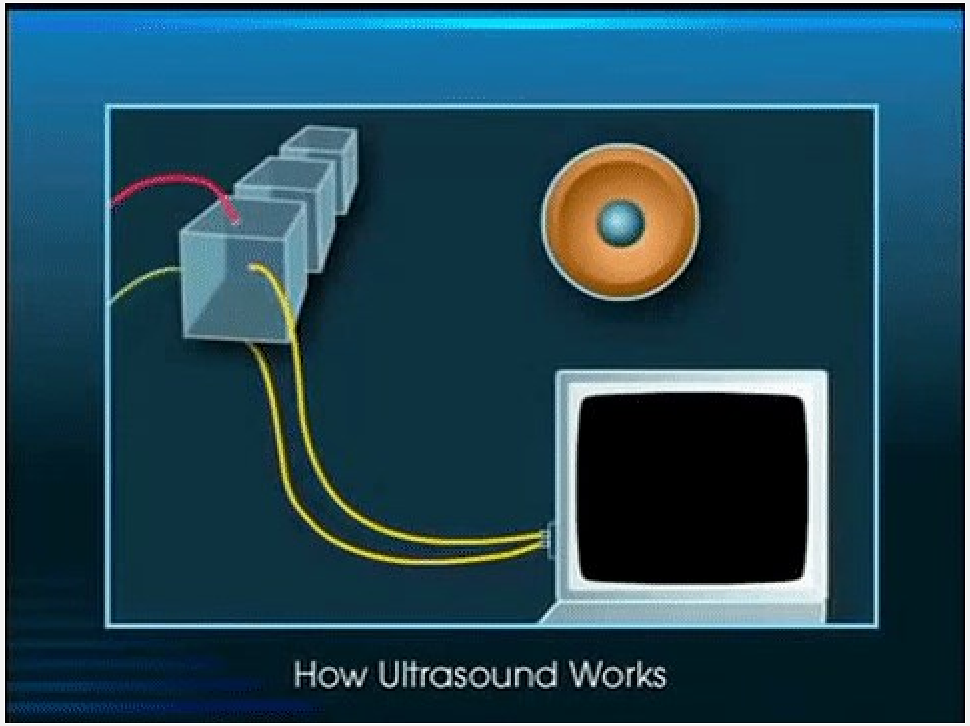


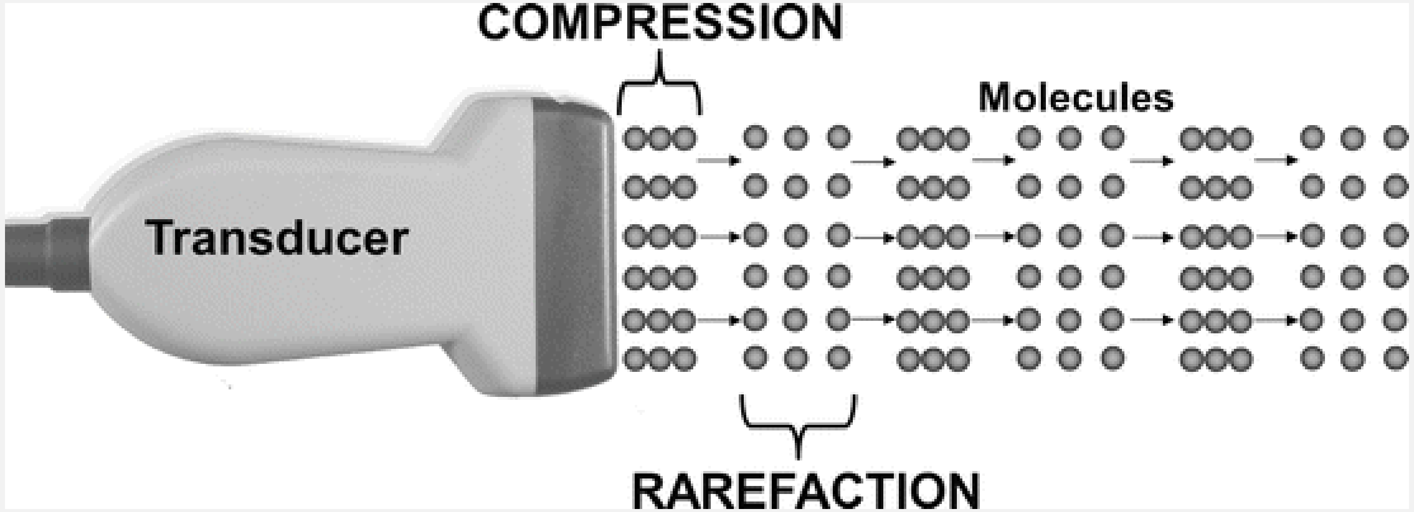
- Se la sorgente è di forma sferica, oppure se può essere considerata puntiforme (approssimazione valida a distanze grandi rispetto alle dimensioni della sorgente stessa), i fronti d’onda sono delle sfere concentriche, e si parla di ONDA SFERICA

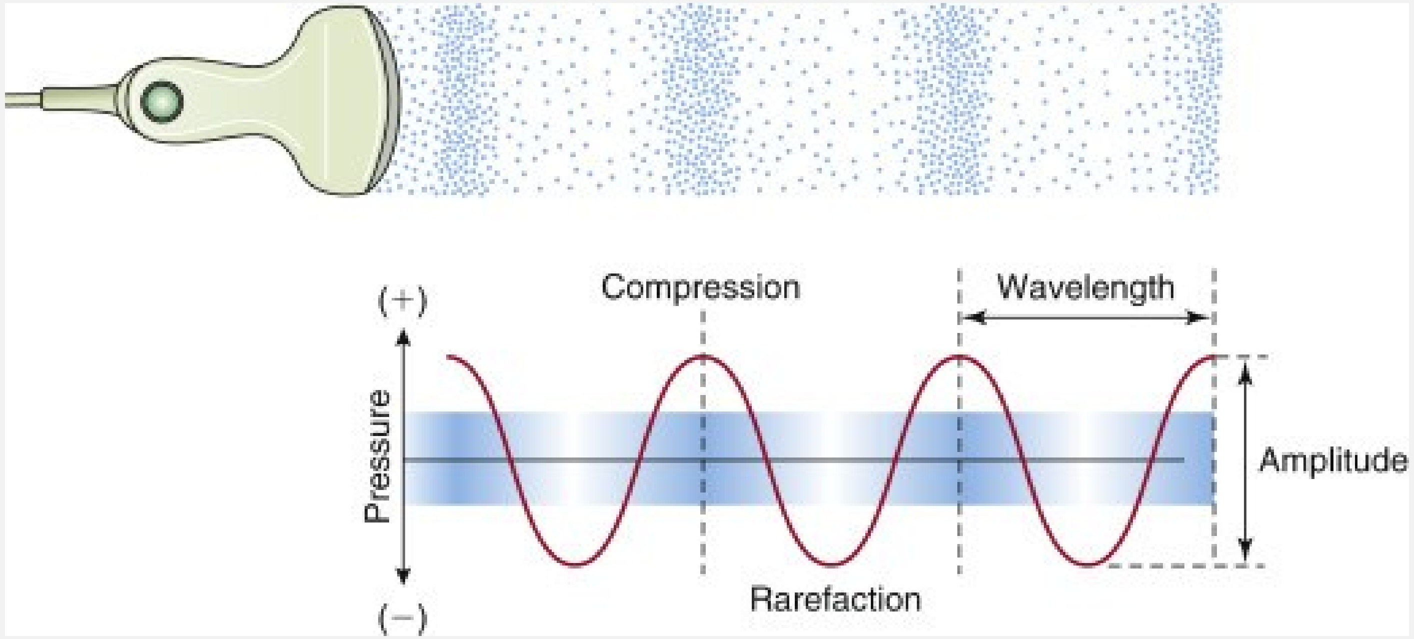
PRODUZIONE DI ULTRASUONI

Effetto piezoelettrico: alcuni particolari cristalli, detti piezolettrici (come il PZT - Titanato Zirconato di Piombo), se sottoposti ad una d.d.p. alternata vibrano con la stessa frequenza del campo elettrico; viceversa, se posti in vibrazione, generano una d.d.p. alternata con la stessa frequenza della vibrazione.






COMPRESSION
Molecules
Transducer
RAREFACTION


(+)
Compression
Wavelength
Pressure
Amplitude
Rarefaction
(−)

Impedenza acustica Z del mezzo

$$Z = c\rho$$

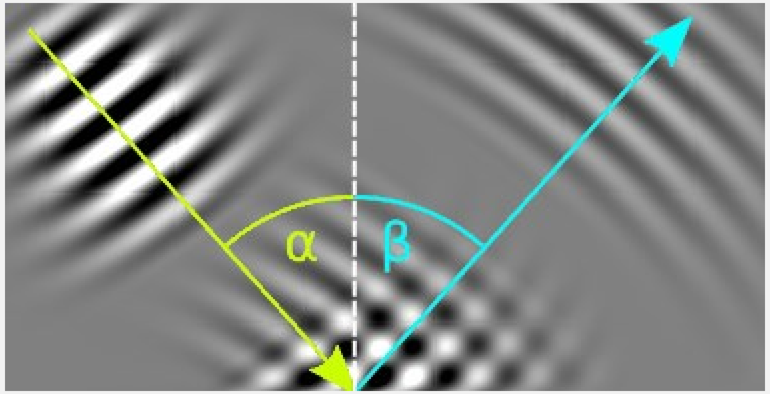
Si misura in $kg/(m^2s)$ e risulta essere praticamente indipendente dalla frequenza.

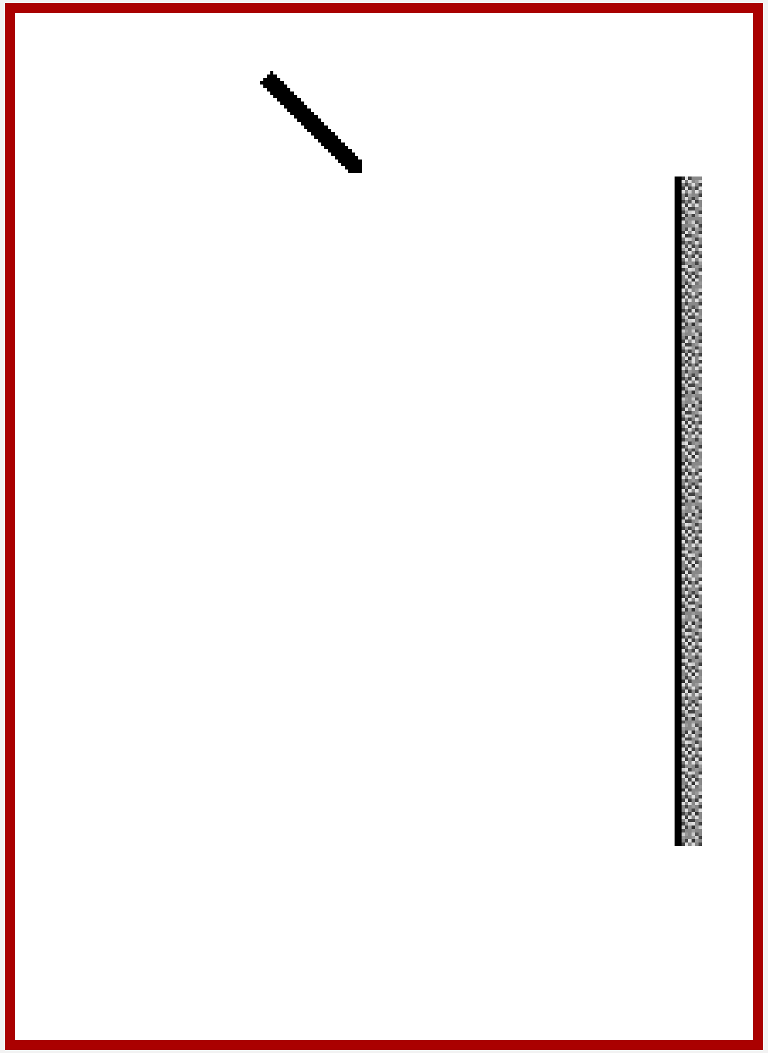
Le superfici di discontinuità (interfacce) fra due mezzi con Z diversi generano sia la RIFLESSIONE che la RIFRAZIONE dell'onda

RIFLESSIONE

$$\theta_{inc} = \theta_{rifl}$$

(l'angolo di incidenza è uguale all'angolo di riflessione)

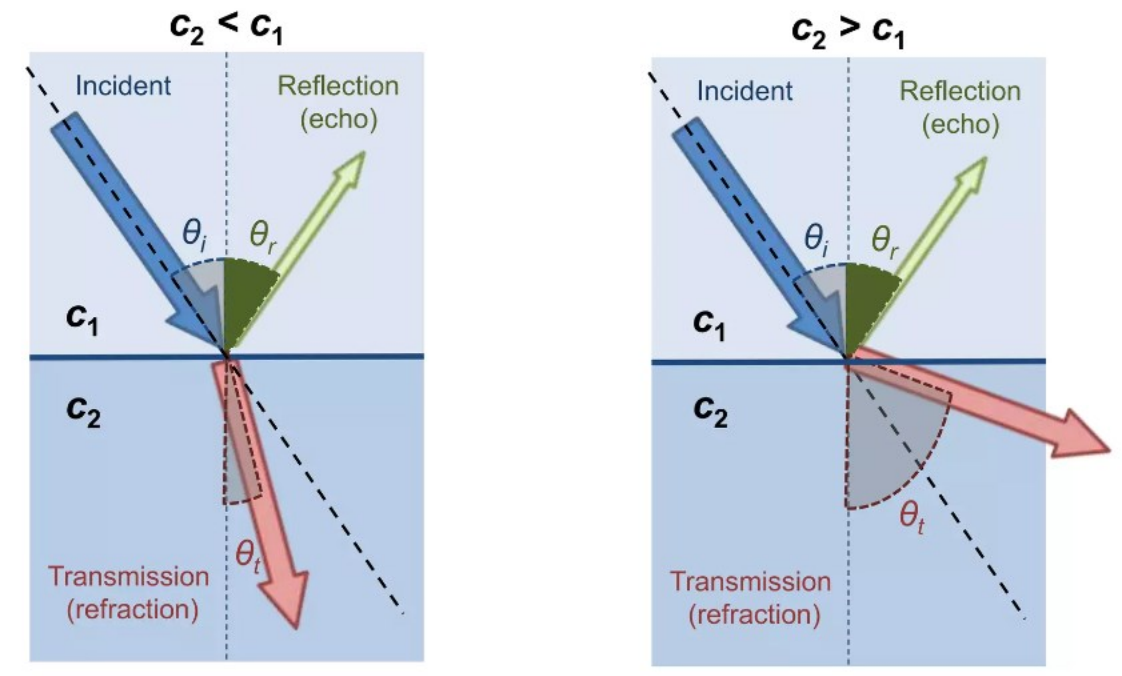


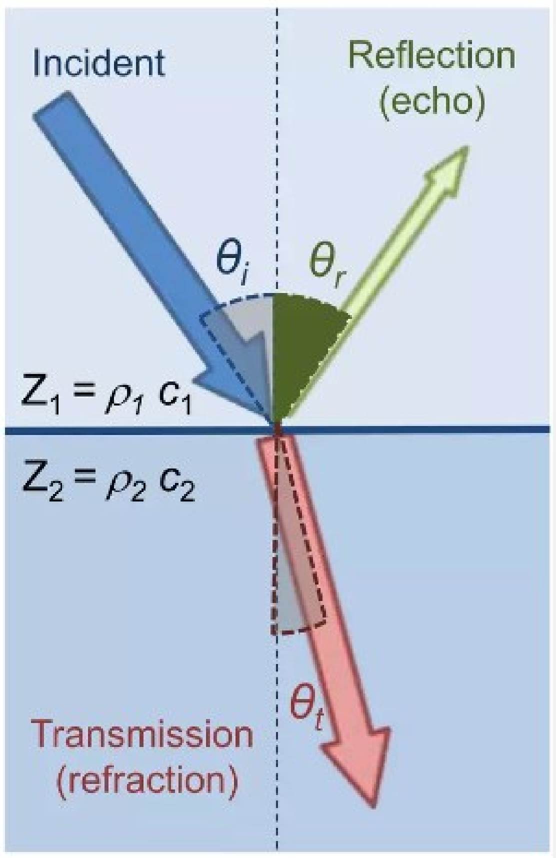


RIFRAZIONE

Tra l’angolo di incidenza e quello di rifrazione vale la relazione nota come legge di Snell:

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$$





RIFRAZIONE

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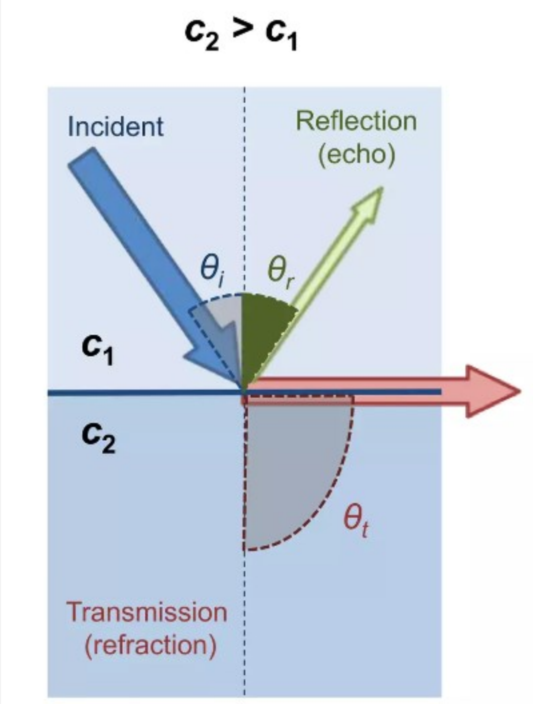
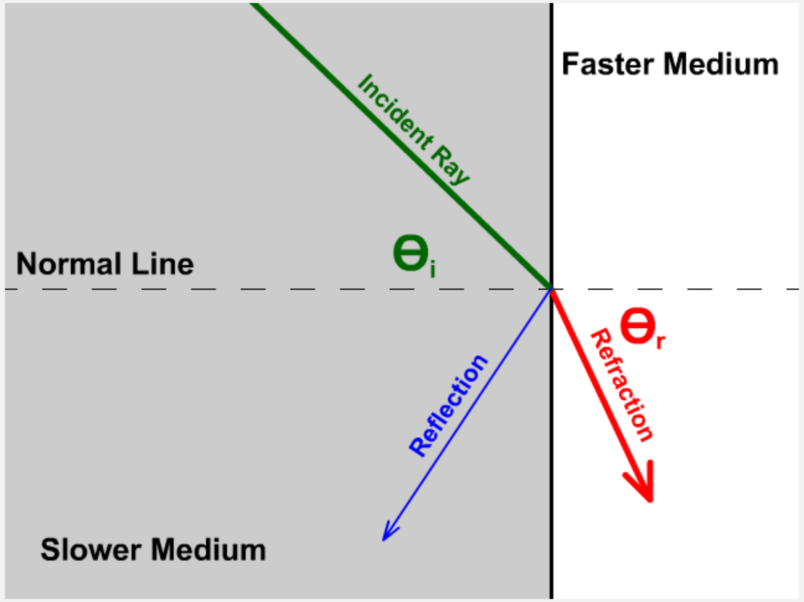


Quando $c_2 > c_1$ e l'angolo incidenza supera un certo angolo limite, si ha riflessione totale

Ottengo che $\theta_2 = 90°$

(può avvenire solo se $c_1 < c_2$!!!)



Coefficienti di riflessione (*R*) e rifrazione (o trasmissione, *T*):

rapporto tra l'intensità riflessa (I_R) o trasmessa (I_T) e quella incidente (I_0)

$$R = \frac{I_R}{I_0} = \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2$$

$$T = \frac{I_T}{I_0} = \frac{I_0 - I_R}{I_0} = 1 - \frac{I_R}{I_0} = 1 - \left(\frac{Z_1 - Z_2}{Z_1 + Z_2}\right)^2 = \frac{4Z_1Z_2}{(Z_1 + Z_2)^2}$$

Dove Z_1 e Z_2 sono le impedenze acustiche dei due mezzi, rispettivamente
(Notare la simmetria di comportamento da 1 a 2 e da 2 a 1)

Se $Z_1 \approx Z_2$:

$R \approx 0, \quad T \approx 1$

(Tutta l'intensità oltrepassa indisturbata l'interfaccia)

Se $Z_1 >> Z_2$ o viceversa:

$R \approx 1, \quad T \approx 0$

(Tutta l'intensità viene riflessa all'interfaccia)

Materiale	Velocità di propagazione (m/s)	Densità (Kg/m^3)	Impedenza acustica ($10^6 Kgs/m^2$)
Aria	331	1.2	0.0004
Acqua	1498	997	1.493
Sangue	1560	1050	1.638
Muscolo	1570	1060	1.642
Osso	3360	1850	6.216

- Valori di *Z* molto simili per diversi istotipi di tessuti molli (muscolo, grasso, sangue) rendono complessa la loro differenziazione ecografica

- Notevoli differenze in *Z* tra aria e tessuti rendono necessaria l'interposizione di un gel tra sonda e cute, per minimizzare le riflessioni da parte dell'aria interposta

ATTENUAZIONE (ASSORBIMENTO)

- Dissipazione di energia nel mezzo (trasformata in calore).

- È legata alla frequenza del fascio, nonché alla viscosità e al tempo di rilassamento (velocità con cui le molecole ritornano alla loro posizione originale) del mezzo.

- Tempo di rilassamento breve → le molecole tornano in posizione primaria prima della successiva onda di compressione.

- Tempo di rilassamento lungo → mentre le molecole stanno tornando in posizione primaria arriva la successiva onda di compressione → è richiesta più energia per invertire il moto → produzione di più calore.

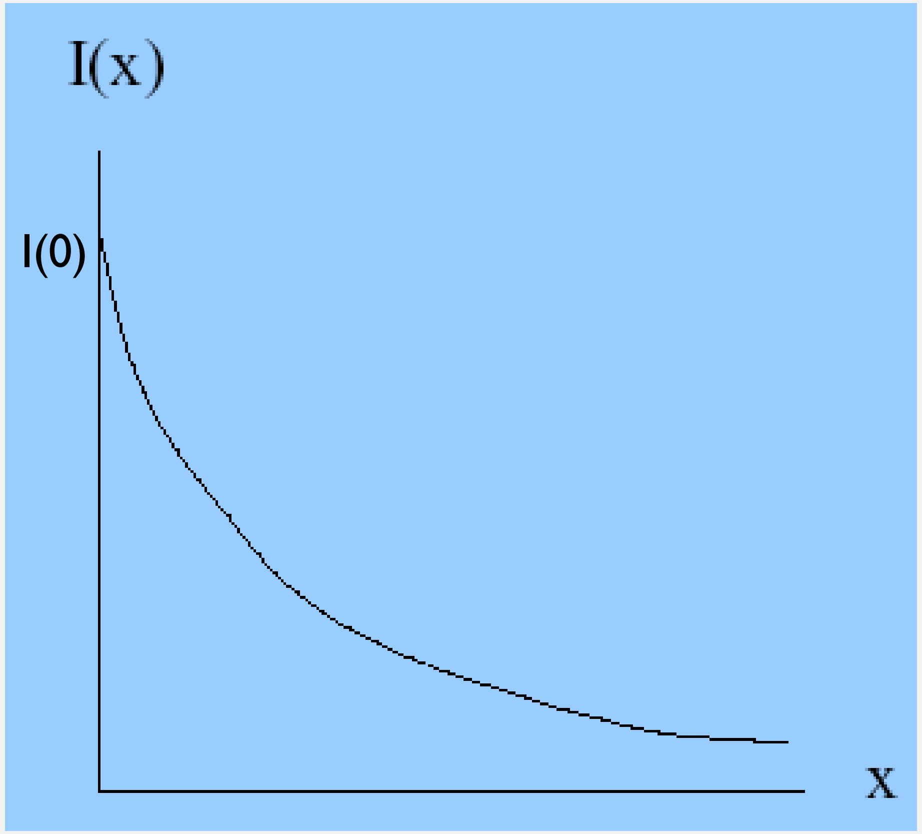
- Alta viscosità → maggior resistenza al movimento delle molecole → maggior calore.

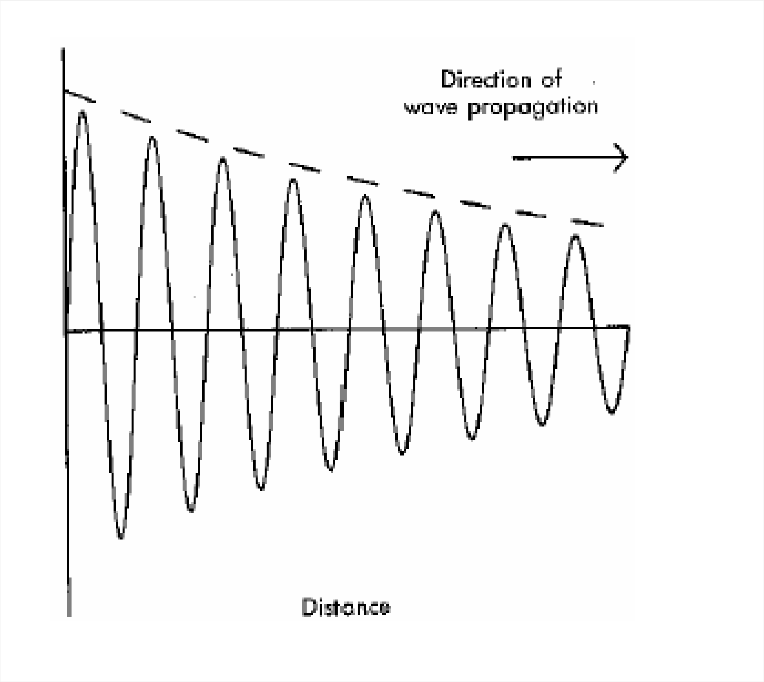
- Frequenze più elevate inducono movimenti più veloci che sono maggiormente ostacolati da viscosità e tempo di rilassamento → maggior calore.

Intensità del fascio ultrasonoro in funzione della profondità

$$I(x) = I(0)\, e^{-\alpha x}$$

α = <u>coefficiente di attenuazione</u>



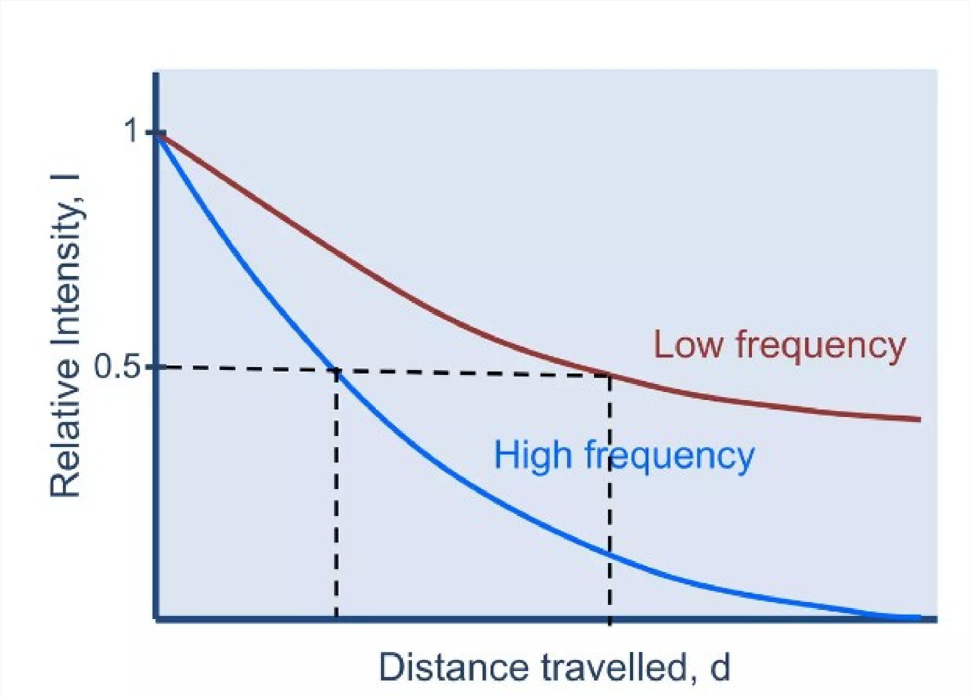


In generale il coefficiente di attenuazione dipende dalla frequenza:

$$\alpha \propto \nu^2$$

Pertanto:

- gli ultrasuoni hanno un limitato potere di penetrazione
- quelli di più bassa frequenza penetrano più in profondità



- Dato l'andamento esponenziale dell'intensità in funzione della profondità, è preferibile esprimere l'attenuazione in <u>decibel</u> (dB):

$$Att\ (dB) = 10 \log_{10}(I_0/I)$$

- Per l'attenuazione degli ultrasuoni nei tessuti molli vale la seguente regola empirica:

Per ogni cm percorso l'attenuazione è pari a 1 dB moltiplicato per la frequenza espressa in MHz

Tissue	**Attenuation Coefficient (1 MHz Beam, dB/cm)**
Water	0.0002
Blood	0.18
Brain	0.3 – 0.5
Liver	0.4 – 0.7
Fat	0.5 – 1.8
Muscle	0.2 – 0.6
Bone	13 - 26
Lung	40

Ultrasuoni ad alta intensità → Intense azioni meccaniche !

Uso degli US in terapia medica:

- Litotrizione (es. frantumazione di calcoli)
- Oftalmologia (interventi sulla cataratta)
- Chirurgia vascolare
- Odontoiatria: eliminazione del tartaro e devitalizzazione dei nervi

Uso degli US in diagnostica medica:

- Ecografia
- Flussimetria Doppler

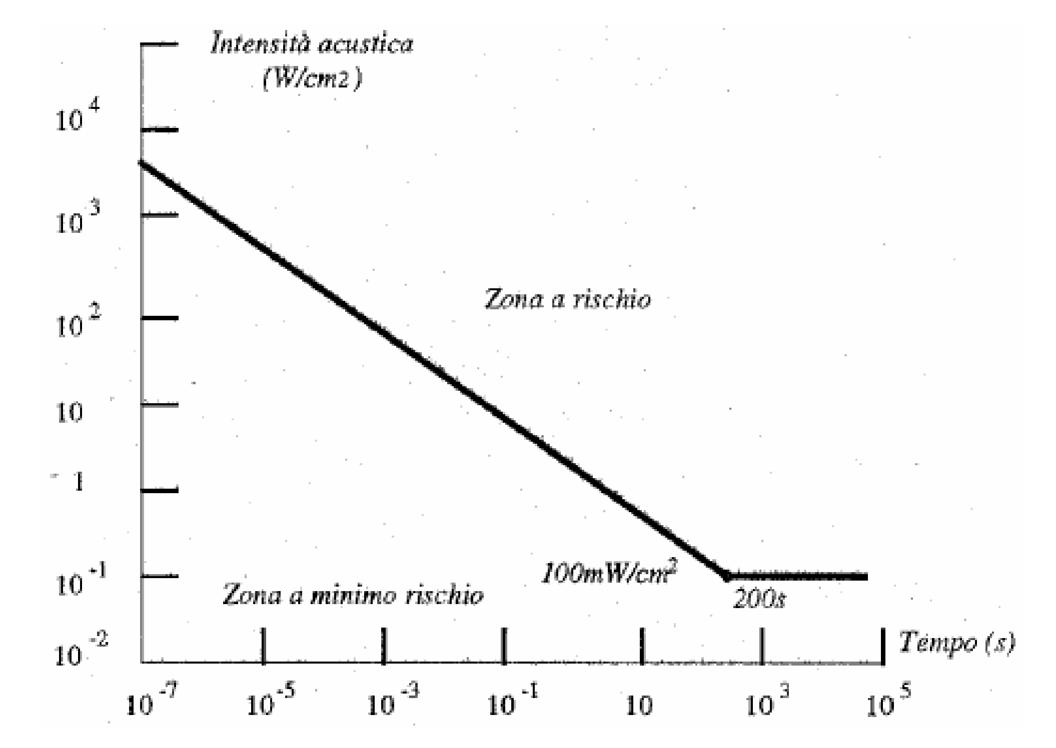
Uso degli US nelle biotecnologie:

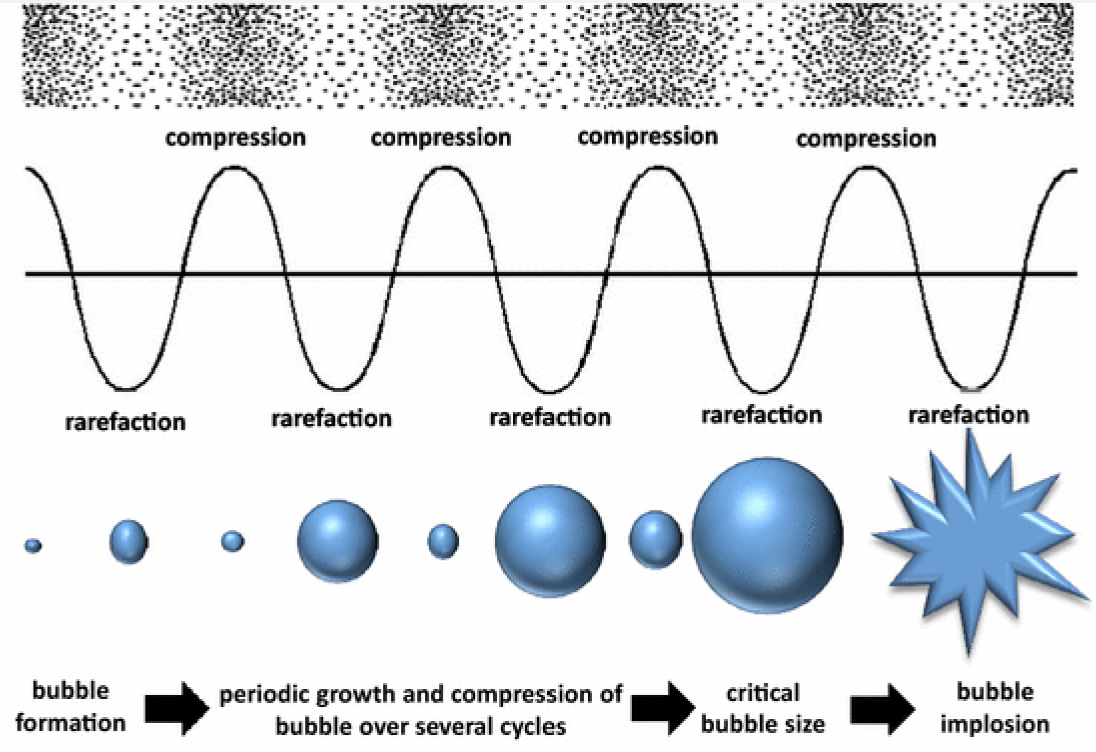
- Ultrasonicazione

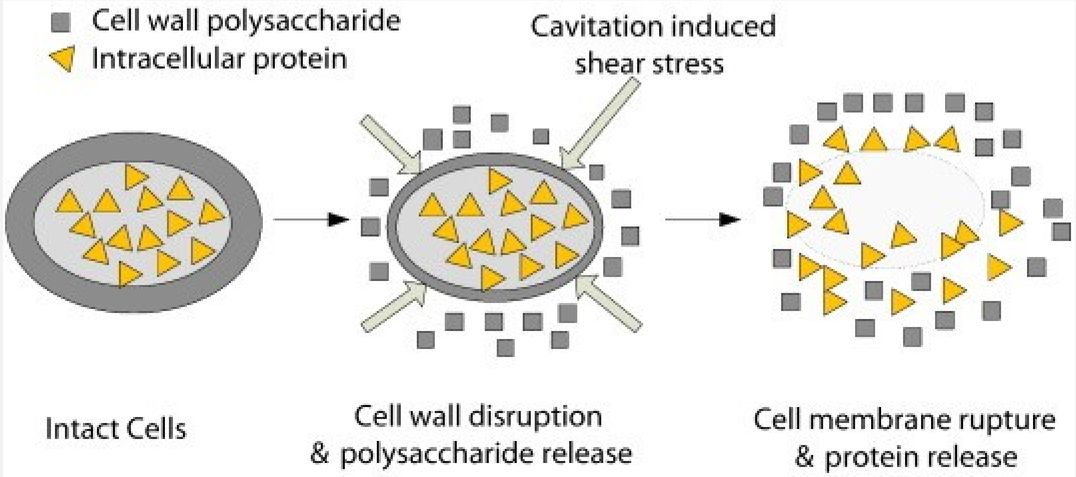
Effetti degli ultrasuoni sui tessuti biologici

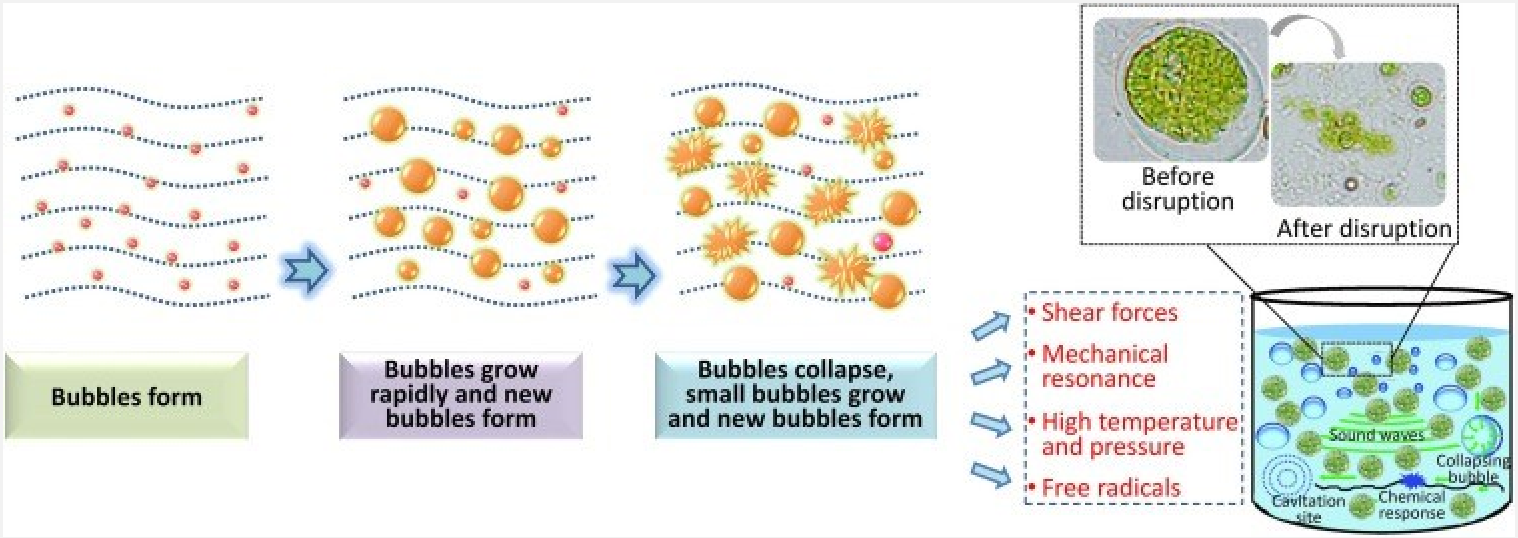
• a bassa intensità attraversano i tessuti biologici senza alterarli
• ad alta intensità, possono produrre il riscaldamento e la cavitazione (generazione di bolle d'aria), alterandone così il funzionamento

Per un fascio di ultrasuoni con frequenza tra 0.5 e 6 MHz





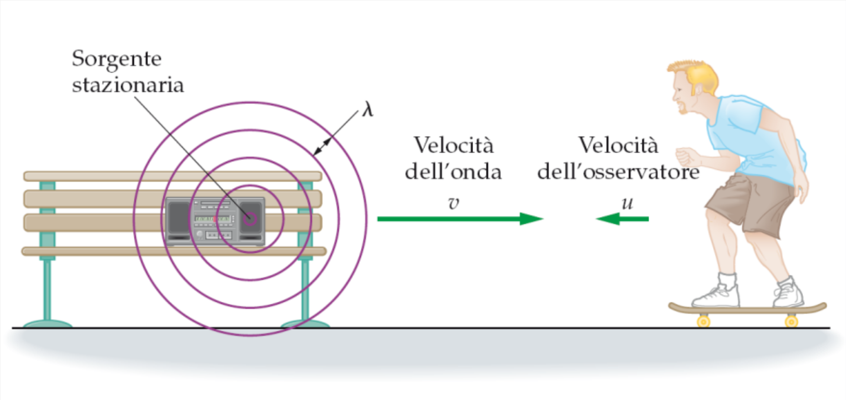

Cell wall polysaccharide
Intracellular protein
Cavitation induced shear stress
Intact Cells
Cell wall disruption & polysaccharide release
Cell membrane rupture & protein release


Bubbles form
Bubbles grow rapidly and new bubbles form
Bubbles collapse, small bubbles grow and new bubbles form
Shear forces
Mechanical resonance
High temperature and pressure
Free radicals
Before disruption
After disruption
Sound waves
Collapsing bubble
Cavitation site
Chemical response

Effetto Doppler

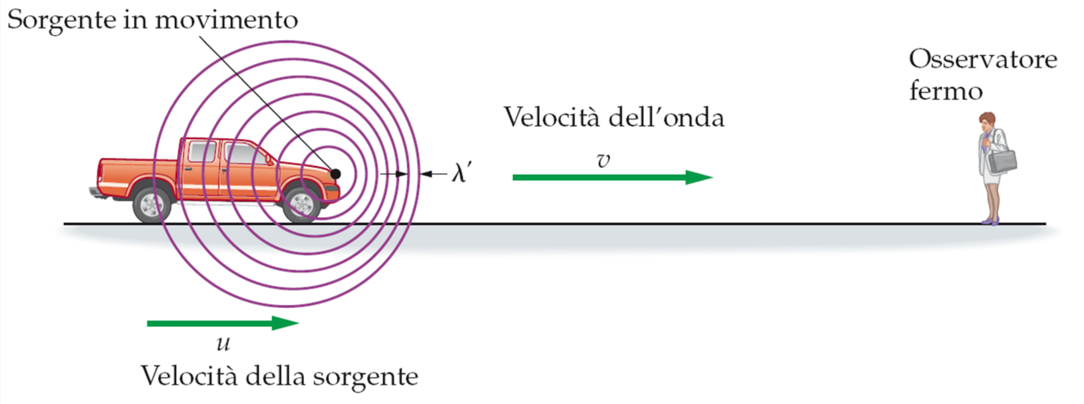
variazione del tono di un suono quando c'è un moto relativo tra la sorgente e l'osservatore

Quando è l'osservatore a muoversi verso la sorgente, il suono sembra avere una velocità maggiore e una frequenza maggiore



Nel caso di una sorgente in movimento l'analisi dell'effetto Doppler è analoga: ma è la lunghezza d'onda che appare diversa

$$\nu = \left(\frac{1}{1 \mp u/V}\right)\nu_s$$



ν=frequenza percepita

ν_s=frequenza emessa dalla sorgente

u=velocità sorgente

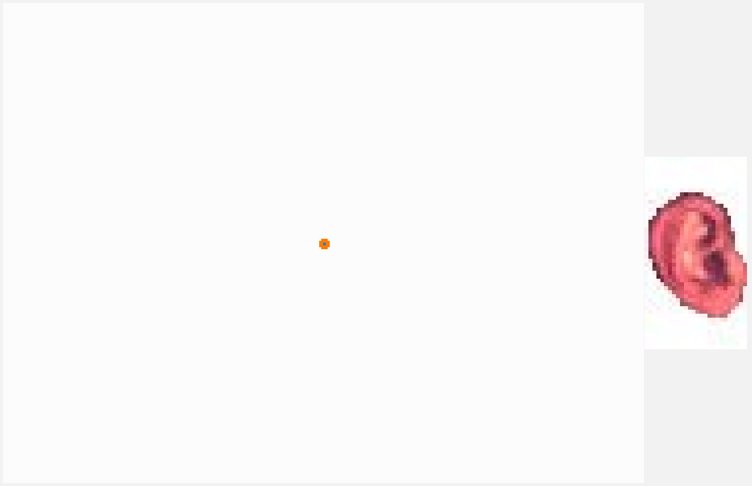
V=velocità onda

Effetto Doppler

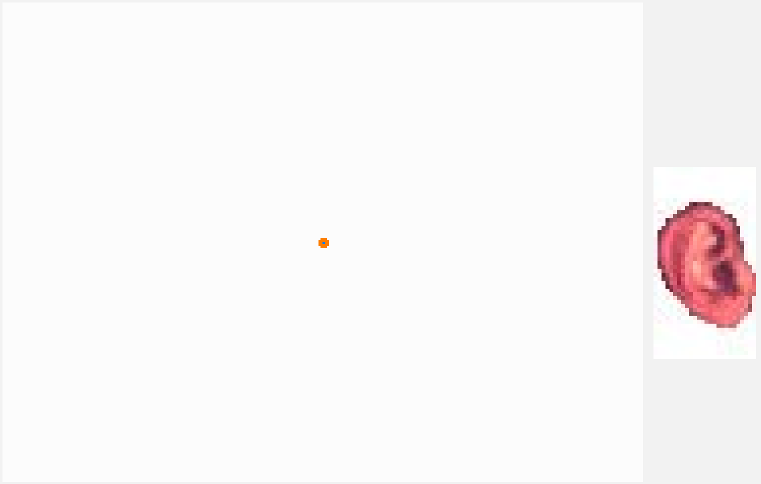
(sorgente sonora in moto rispetto all'osservatore)

La frequenza percepita dall'osservatore (ν) è diversa da quella emessa dalla sorgente (ν_0)

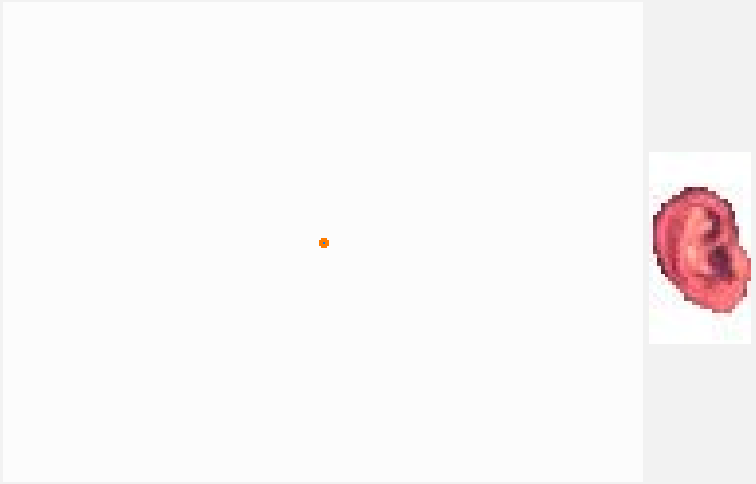
Sorgente in quiete (ν_0)



Sorgente in avvicinamento ($\nu > \nu_0$)



Sorgente in allontanamento ($\nu < \nu_0$)



Flussimetria Doppler

Consideriamo un vaso sanguigno, al cui interno si trovano, immersi nel plasma, anche corpuscoli (globuli bianchi, piastrine, ma soprattutto globuli rossi), e inviamo un fascio di US di frequenza ν_0 che intercetta un globulo rosso:

- Gli US verranno ricevuti dal globulo in moto con velocità *v* che, riflettendoli, verrà a sua volta visto dal ricevitore come una sorgente in moto

- il ricevitore misurerà pertanto US di frequenza $\nu = \nu_0 + \Delta\nu$ (*Doppler shift*), in cui:

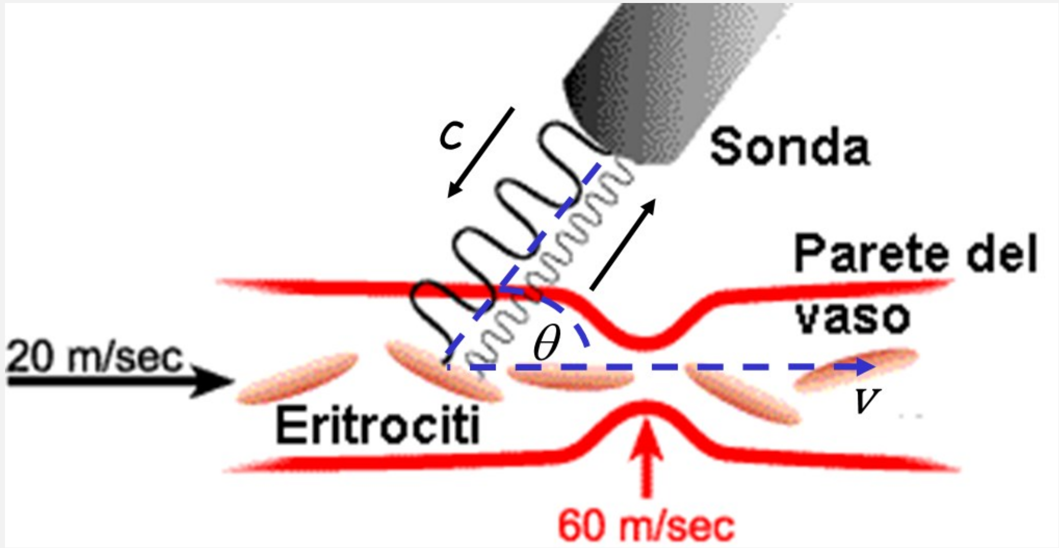
$$\Delta\nu = \pm\nu_0 \frac{2V}{c} cos\theta$$

ν_0=frequenza emessa dalla sorgente

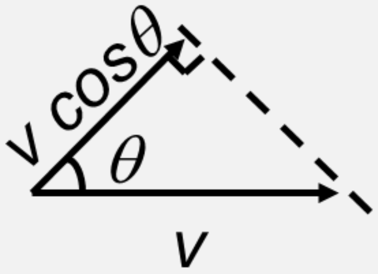
V=velocità sorgente

c=velocità propagazione onda

(il segno + vale per la sorgente in avvicinamento, il segno – vale per la sorgente in allontanamento)



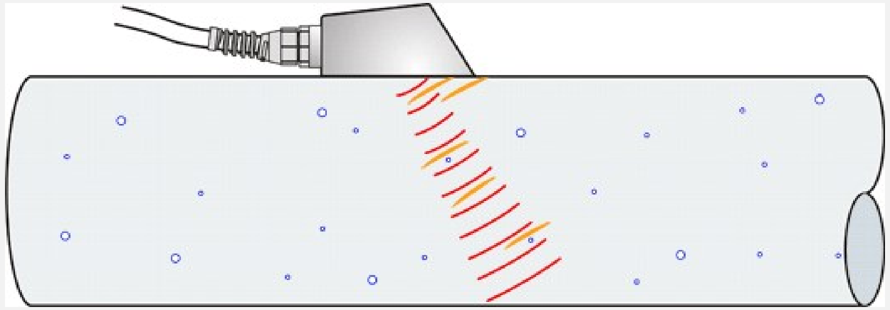
$$\Delta\nu = \pm\nu_0 \frac{2V}{c} cos\theta$$



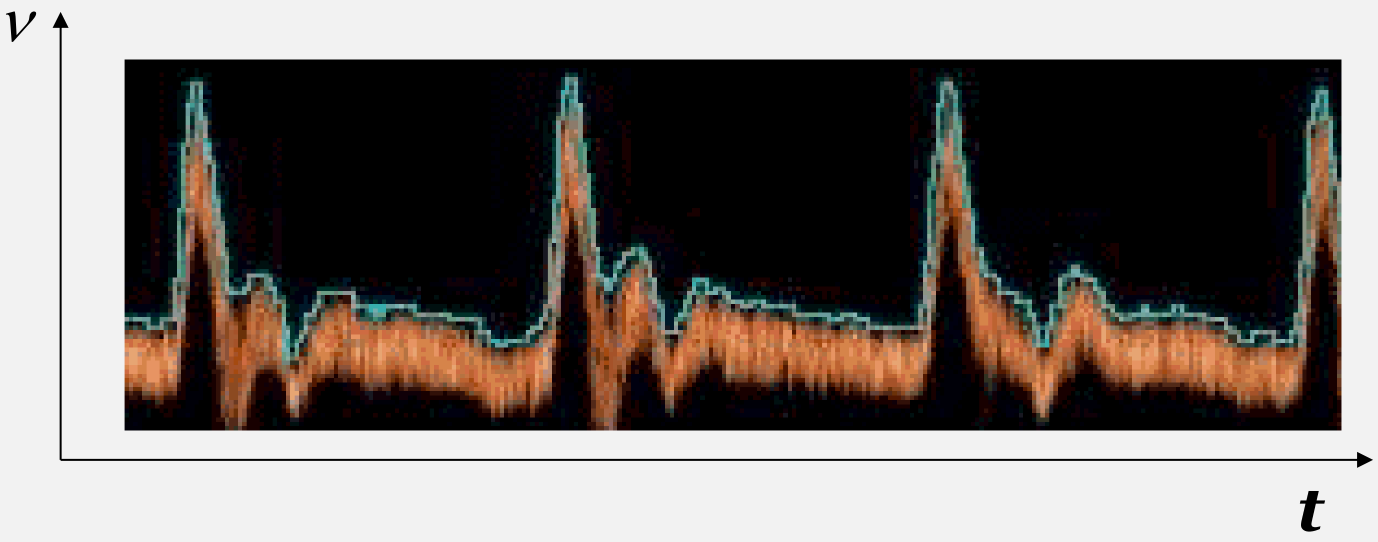
- Se il fascio di US è perpendicolare al flusso non si ha effetto Doppler ($cos\theta = 0$)

- Affinché il *Doppler shift* sia massimo, e quindi più facilmente misurabile, è necessario che la direzione del fascio si avvicini il più possibile a quella parallela al flusso ($cos\theta = 1$)

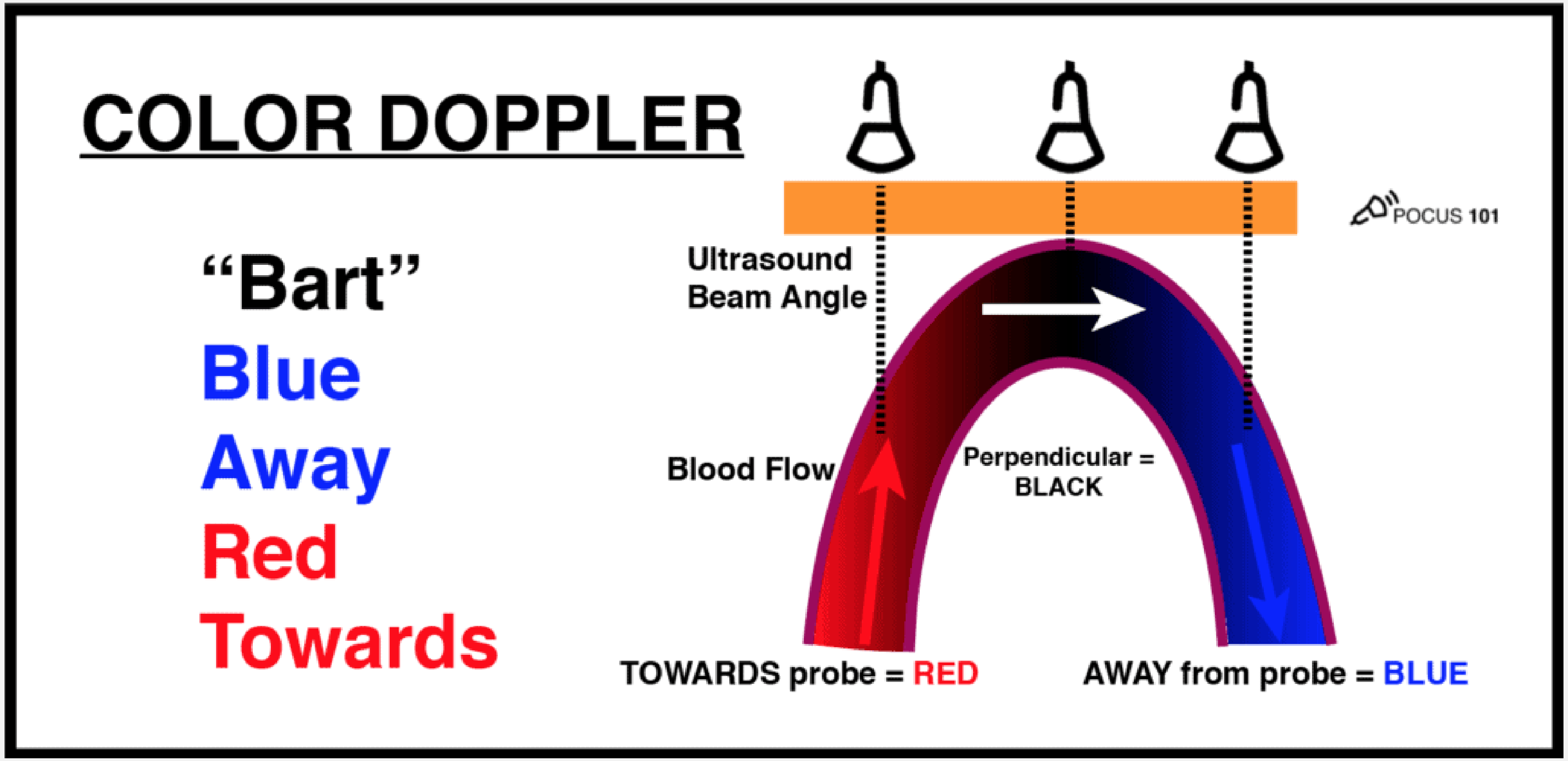
- In prima approssimazione si considera che questa condizione è sufficientemente soddisfatta se $\theta \approx 40°\text{-}50°$



$$\Delta\nu = \pm\nu_0 \frac{2V}{c} cos\theta$$



Rappresentazione grafica del segnale Doppler con l'accelerazione del flusso durante ogni battito cardiaco.


COLOR DOPPLER
“Bart”
Blue
Away
Red
Towards
POCUS 101
Ultrasound
Beam Angle
Blood Flow
Perpendicular =
BLACK
TOWARDS probe = RED
AWAY from probe = BLUE

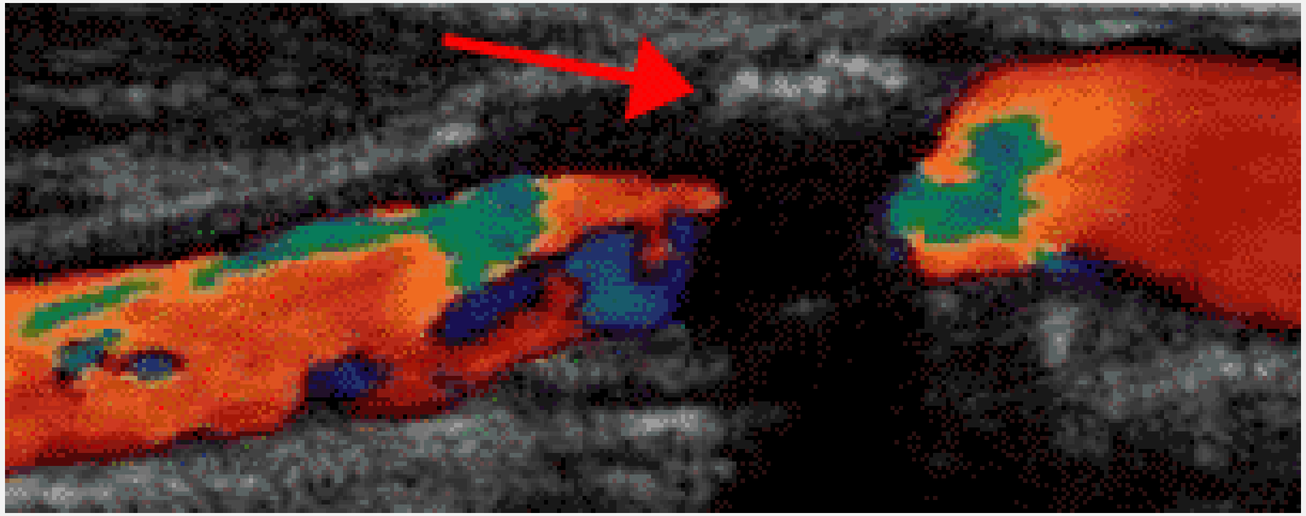


Immagine Duplex di un restringimento dell'arteria carotide del collo. Il flusso del sangue è rappresentato a colori. In mezzo si riconosce una placca arteriosclerotica (freccia) che riduce il flusso ed essendo calcificata causa un'attenuazione del segnale (ombra sotto la placca).