Ultrasound

Ultrasound is sound waves of high frequency (> 20 kHz), high energy that can penetrate matter.

Ultrasound Generation

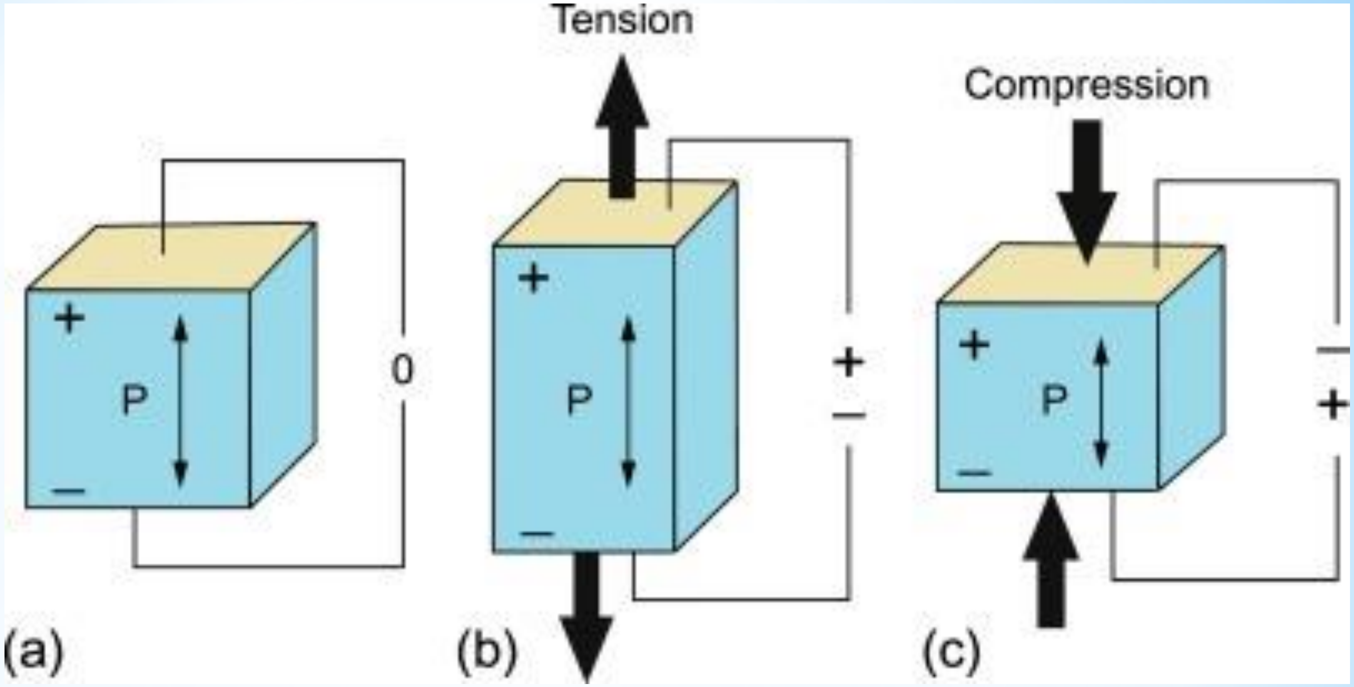
Piezoelectric Effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. The word **Piezoelectric** is derived from the Greek piezein, which means to squeeze or press, and piezo, which is Greek for "push".

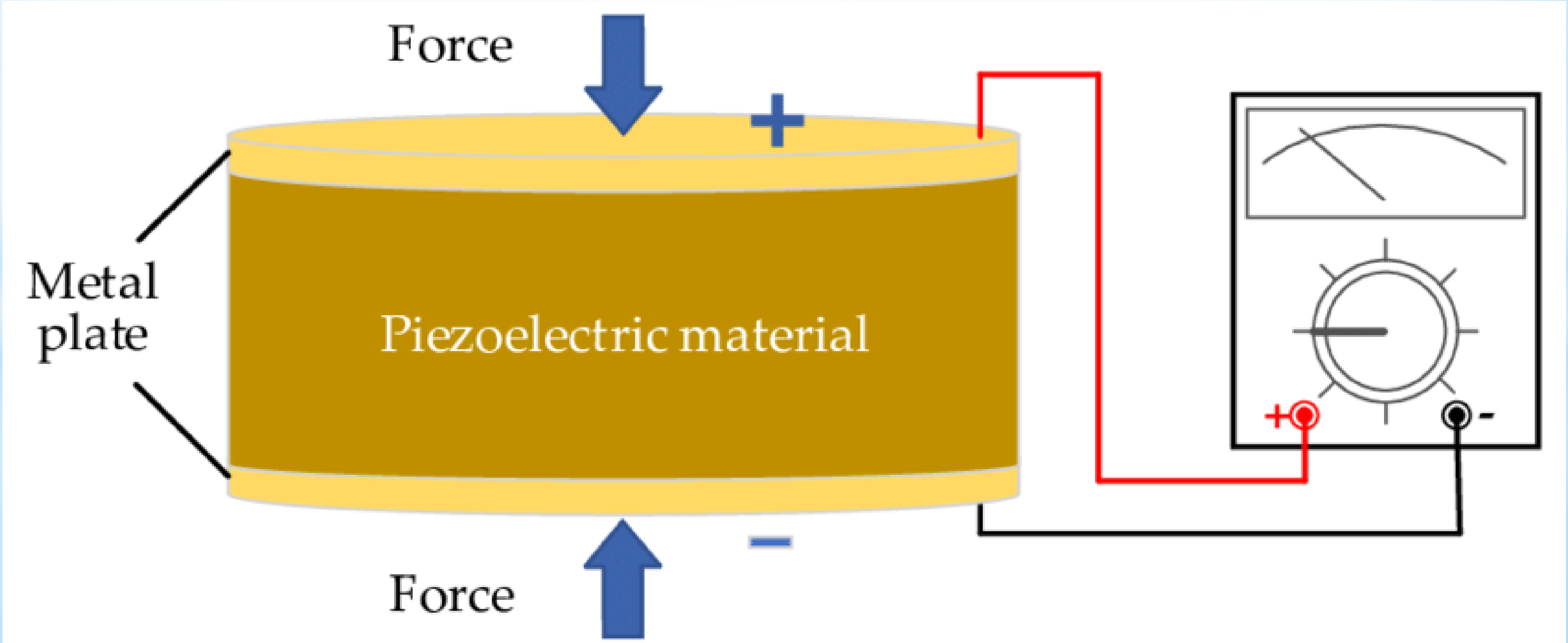
Piezoelectricity is the electric charge that accumulates in certain solid materials in response to applied mechanical stress. The word piezoelectricity means electricity resulting from pressure and heat.

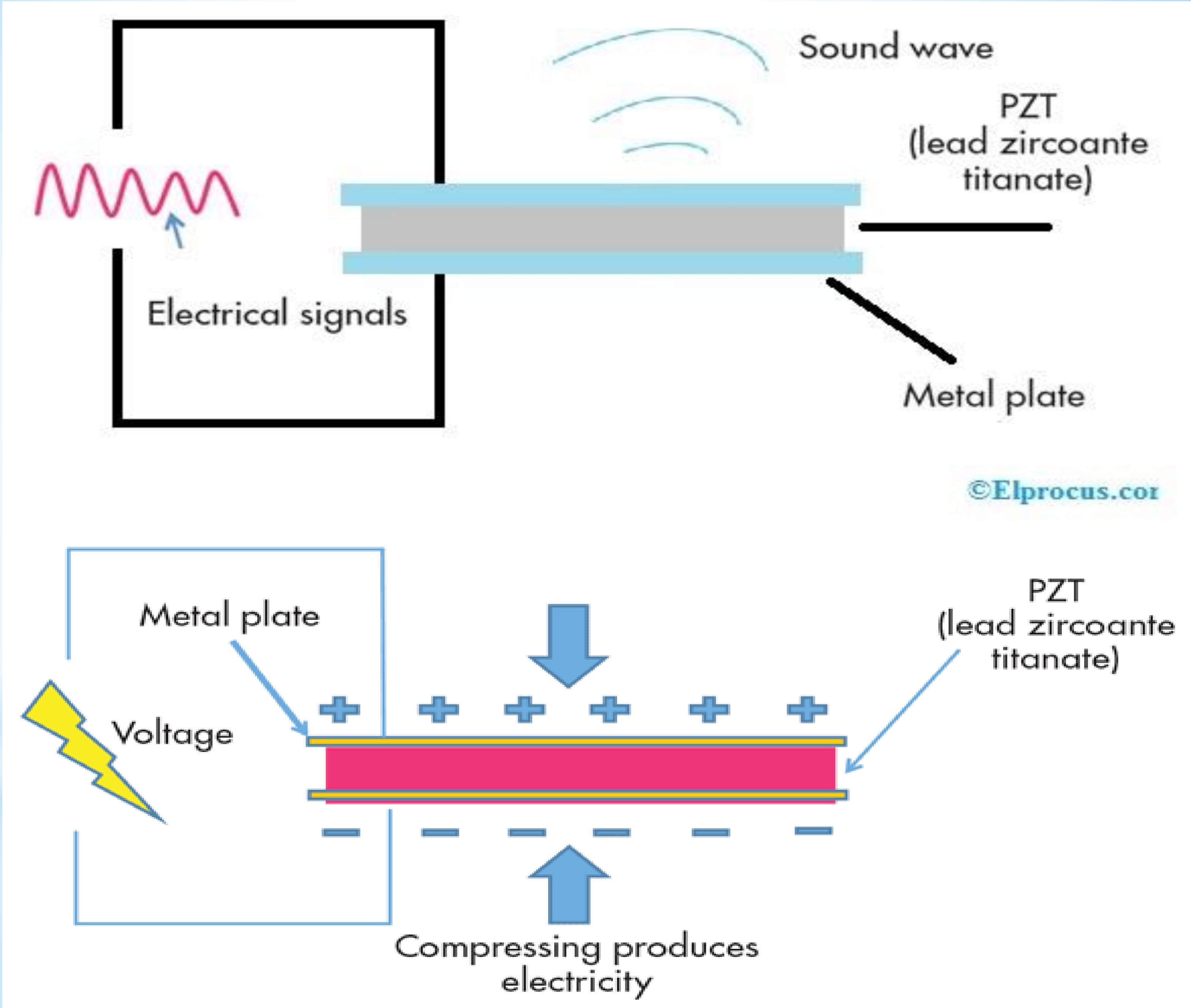
Ultrasound Generation

- When an electric current is applied **to** a **piezoelectric crystal**, it starts **to** vibrate and these vibrations generate sound waves with frequencies between 1.5 and 8 MHz (i.e **Ultrasound**).
- Thus, piezoelectric crystals can convert electric currents into ultrasound waves.
- The thinner piezoelectric crystal, the higher ultrasound frequency.

Ultrasound Generation






Sound wave
PZT
(lead zircoante
titanate)
Electrical signals
Metal plate
©Elprocus.cor
Metal plate
Voltage
PZT
(lead zircoante
titanate)
Compressing produces
electricity

Properties of Ultrasound waves:

(1) They have a high energy content.

(2) Just like ordinary sound waves (longitudinal waves, and get reflected, refracted and absorbed.

(3) When an ultrasound wave meets a boundary between two different materials some of it is refracted and some is reflected.

The reflected wave is detected by the ultrasound scanner and forms the image (ultrasonic scanning).

(4) They can be transmitted over large distances with no appreciable loss of energy.

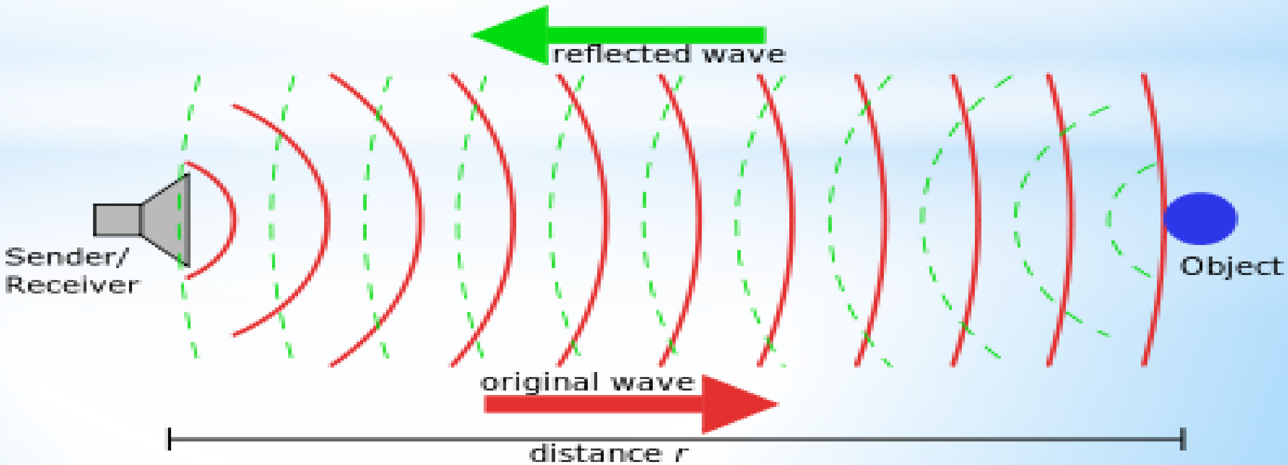
5) They produce intense heating effect when passed through a substance.

6) Ultrasound waves are caused by vibrations and therefore cause no ionization.

And also able to distinguish between muscle and blood and therefore show blood movement.

SONAR *Sound Navigation and Ranging*

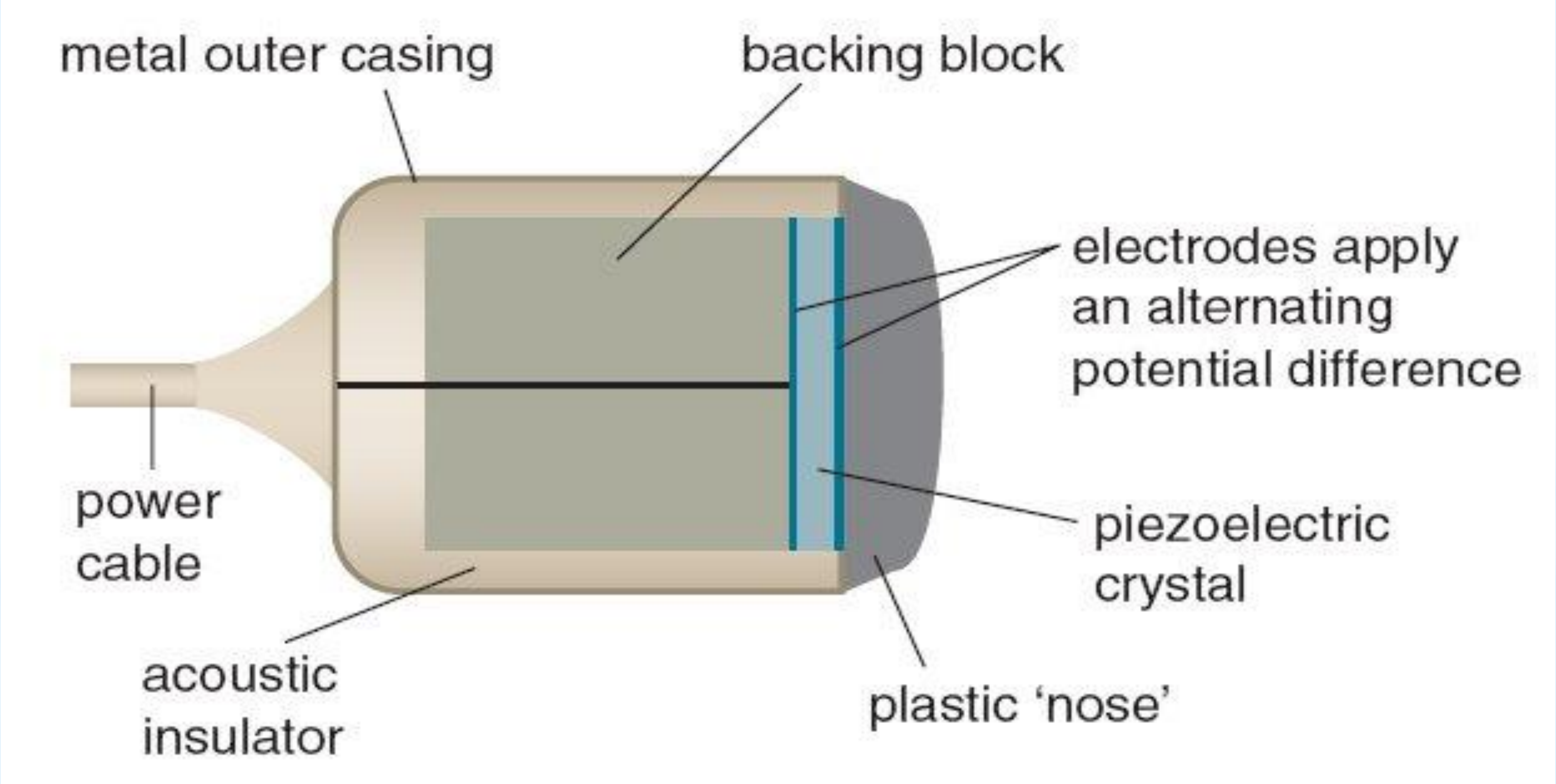
Example: Bats use the sonar principle for navigating and finding objects (food).



Ultrasound transducer

Ultrasound is produced and detected using an ultrasound transducer. Ultrasound transducers are capable of sending an ultrasound and then the same transducer can detect the sound and convert it to an electrical signal to be diagnosed.

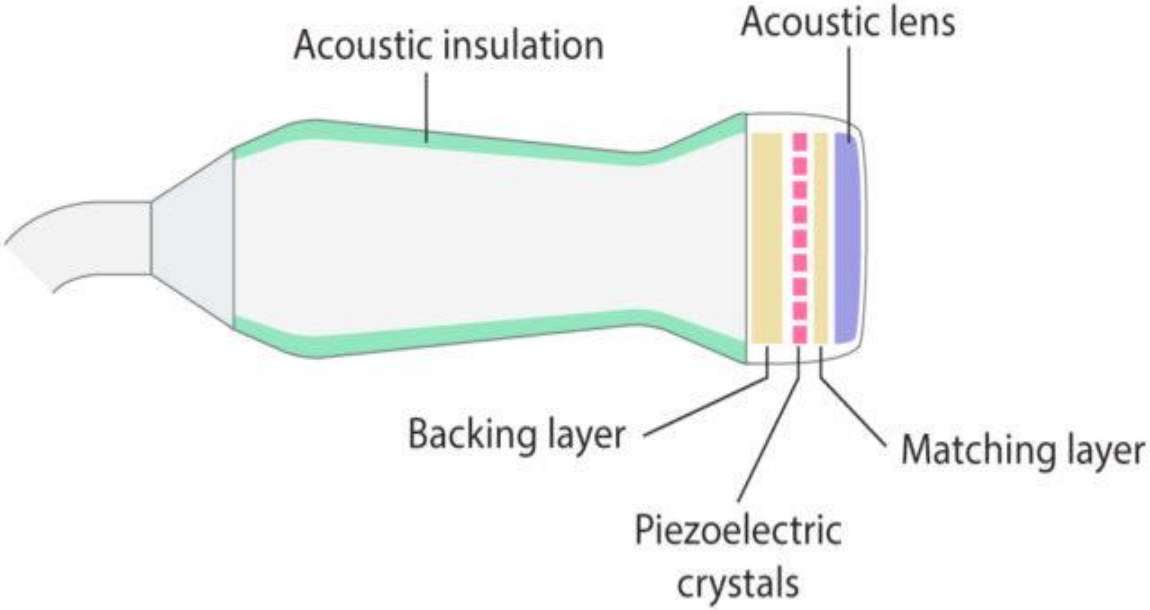
Ultrasound transducer

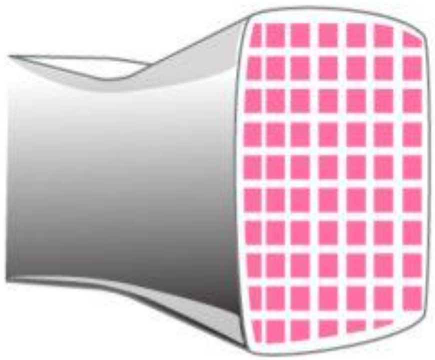


- The thinner piezoelectric crystal, the higher ultrasound frequency.

The ultrasound transducer

The ultrasound transducer from the side and front.





Arrangement of piezoelectric crystals

When the ultrasound fall on an object, then bounces back off the object under investigation.

The sound hits the piezoelectric crystal and then has the reverse effect causing the mechanical energy produced from the sound vibrating the crystal to be converted into electrical energy.

By measuring the time between when the sound was sent and received, the amplitude of the sound and the pitch of the sound, a computer can produce images, calculate depths and calculate speeds.

Application of ultrasound

* It is used for medical diagnosis and therapy and also as a surgical tool.
* It is used to detect defective fetus.
* It is used as a tool in the treatment of muscular pain.
* Ultra sonography (is a technique of 3-dimensional photographs with the help of ultrasonic waves) is used to locate the exact position of an eye tumor.
* Ultrasound is generally used to clean spiral tubes, electronic components etc.
* Ultrasound are used to detect cracks and flaws in metal blocks.

Medical Applications of Ultrasound

Ultrasound has medical applications:
Therapeutic and diagnostic:

- Diagnostic applications such as ultrasound scan (sonograms), which are used to visualize the fetus in the uterus or to evaluate the heart function (echocardiograms). In these techniques a beam of ultrasound is pulsed into the body and the time required for the echoes to return is measured.

- Therapeutic applications such as shock wave lithotripsy (SWL). In this technique, an intense beam of ultrasound is concentrated onto a kidney stone that must be removed. After being hit with many as 1000 to 3000 pulses of sound, the stone is fractured into small pieces that the body can then eliminate on its own.

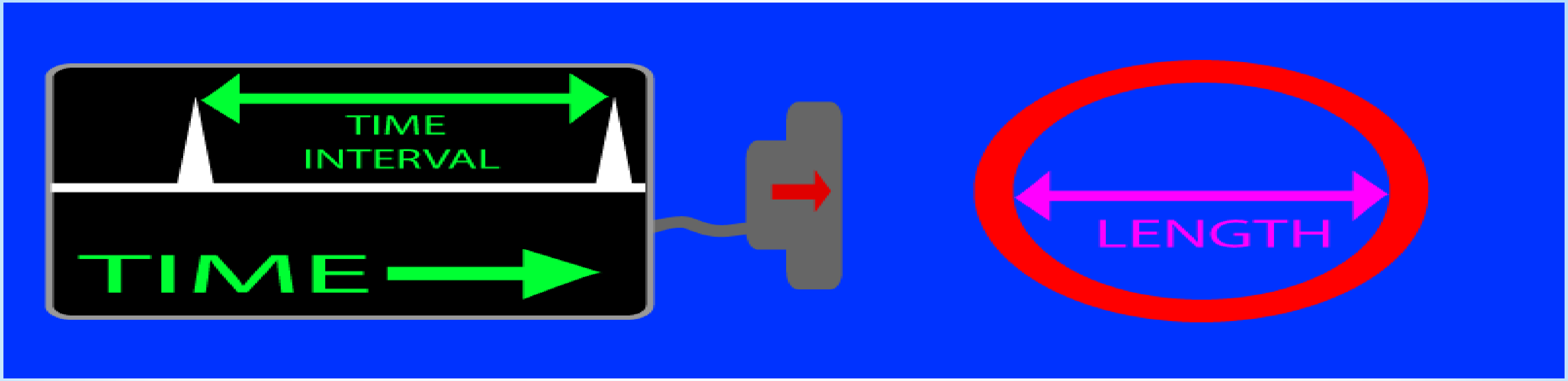
Ultrasound Scan

An ultrasound scan, sometimes called a sonogram, is a procedure that uses high frequency sound waves to create an image of part of the inside of the body, such as the heart.

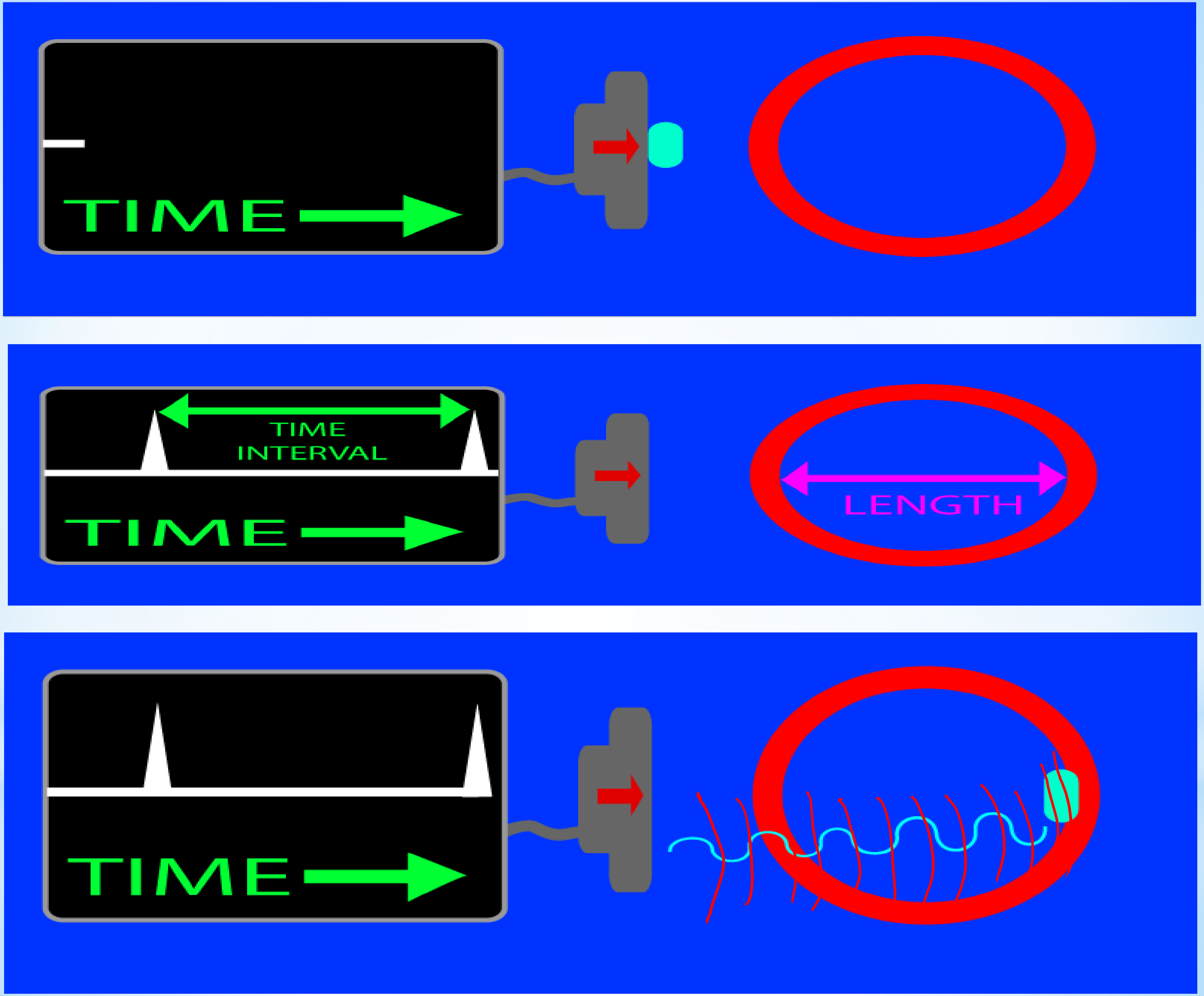
Type of ultrasound Scans

- A Mode Scanning
- B Mode Scanning

A Mode Scanning



- The time difference between the first bump (amplitude) and the second bump represents how long the US wave took to travel between the two walls. Longer the length, longer is the time difference.
- The speed of US in the eye is ~1500 m/sec


TIME
TIME
INTERVAL
LENGTH
TIME
TIME

A-Scan Applications:

(1) Echoencephalography

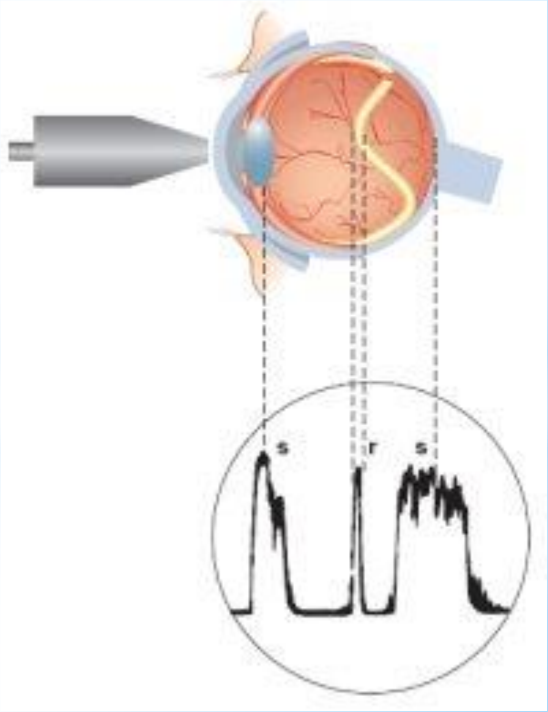
This technique is used in the detection of brain tumors.

(2) Ophthalmology

This technique is used in the diagnosis of eye diseases and in biometry (measurement of distances in the eye).

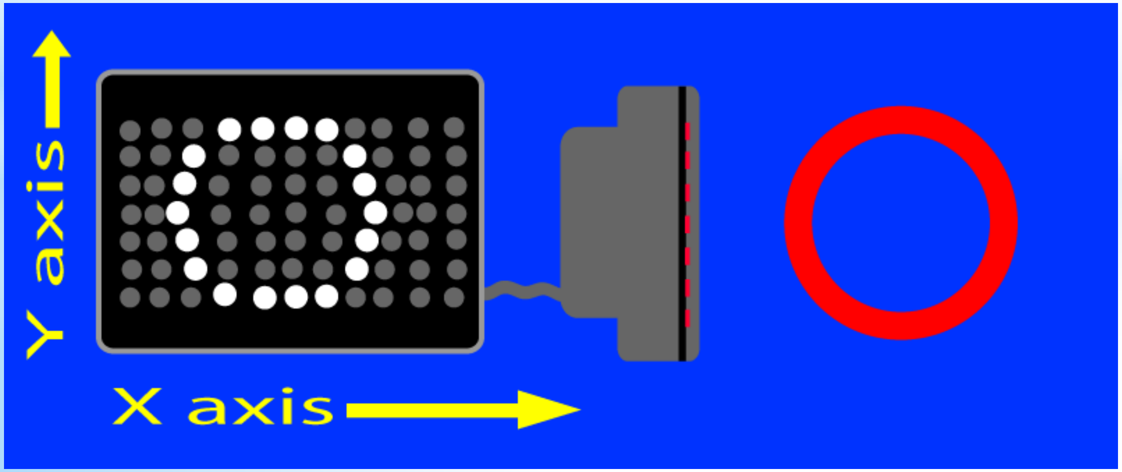
A Mode Scanning

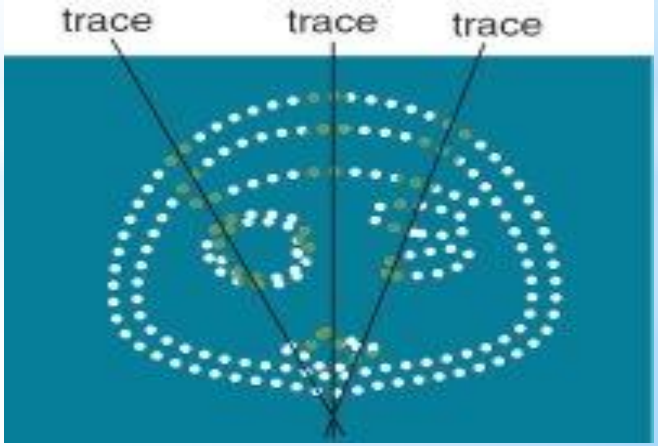
A-scans can be used in order to measure distances.
A transducer emits an ultrasonic pulse and the time taken for the pulse to bounce off an object and come back is graphed in order to determine how far away the object is.
A-scans only give one-dimensional information and therefore are not useful for imaging.
Ophthalmologists can use it to Measure the diameter of the eye ball.



B Mode Scanning

* B-scans can be used to take an image of a cross-section through the body. The transducer is swept across the area and the time taken for pulses to return is used to determine distances, which are plotted as a series of dots on the image. B-Scans will give two-dimensional information about the cross-section



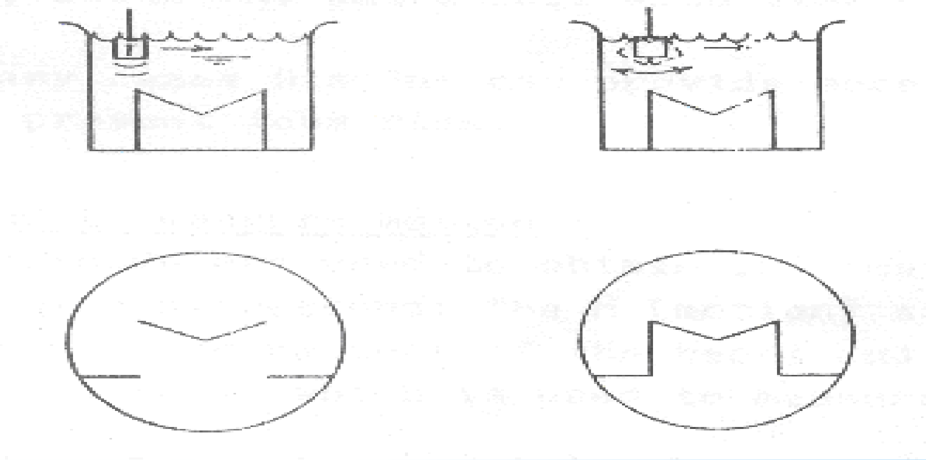


- **B-Scan**

This method is used to obtain two dimensional views of parts of the body. The principles are the same as in A-Scan except that the transducer is moved. Each echo produces a dot on the oscilloscope.

(1) B-scan can be used in the diagnostic of the eye, liver, breast, heart and fetus.

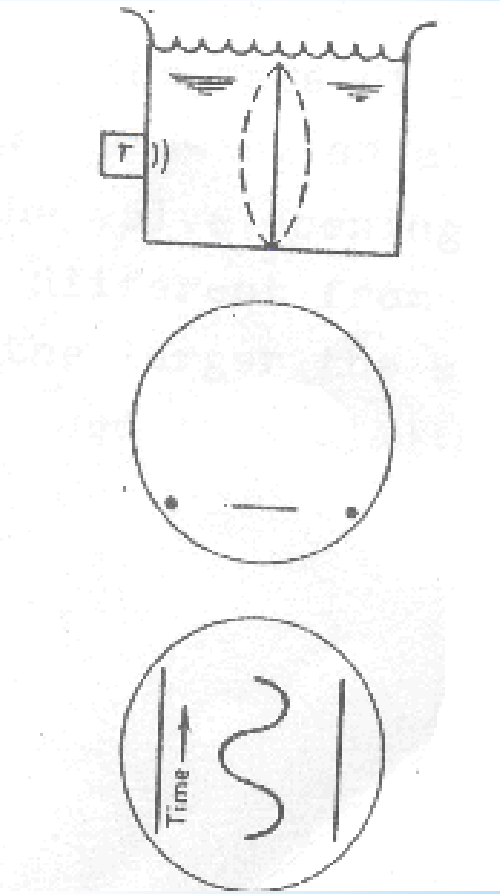
(2) It can provide information about the size, location and change with time of a fetus.



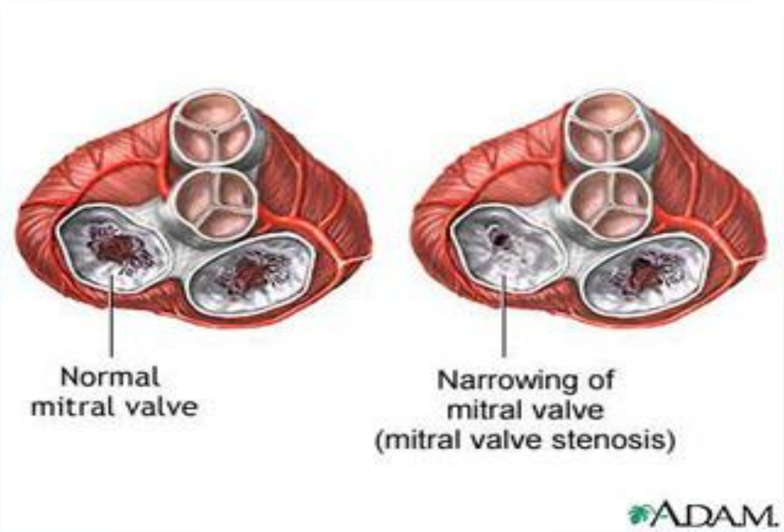
•**M-Scan (Motion Scan)**

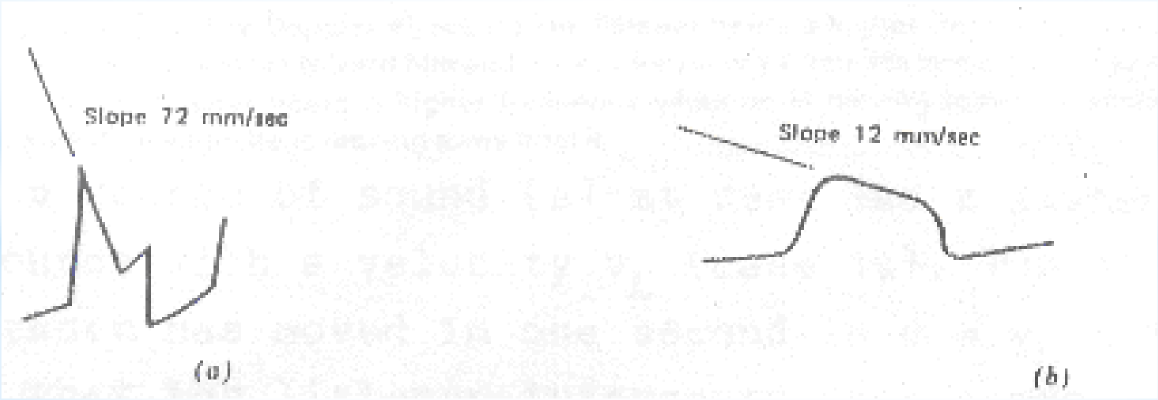
This method is used to obtain information about motion in the body. M-Scan is used to study motion such as that of the heart and heart valves and the Doppler technique which is used to measure blood flow.

M-Scan.



Mitral Stenosis

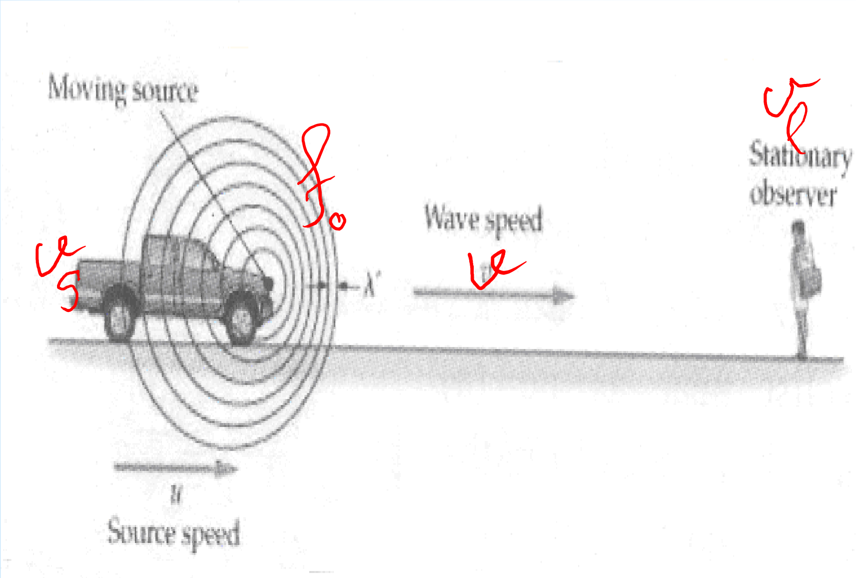


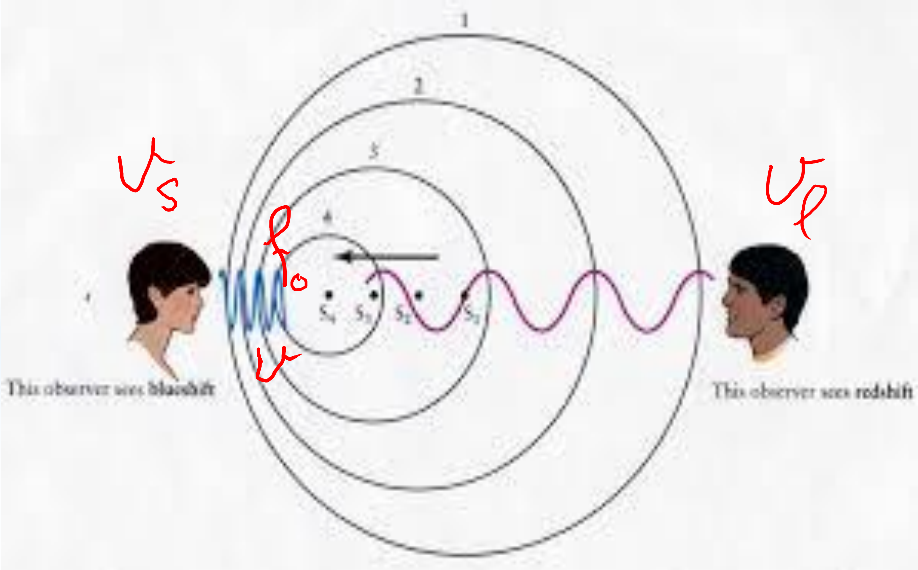


Doppler effect

The Doppler effect was originally postulated by the Austrian scientist Doppler. The effect is responsible for changes in the frequency of waves emitted by moving objects as detected by a stationary observer.

The change in pitch (Sound Frequency Change) due to the relative motion between the sound source and a receiver is called **the Doppler Effect.**





The difference in frequency (Δf) is called the **Doppler frequency shift** , **Doppler shift** or **Doppler frequency**.

The Doppler shift depends on:

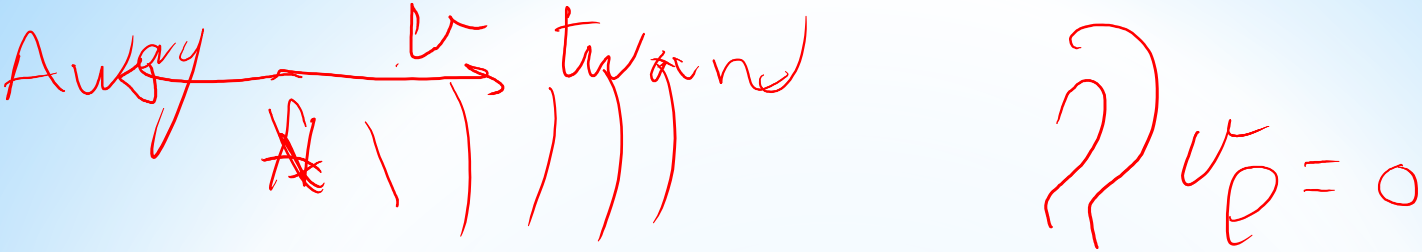
- The emitted sound frequency (f_o).
- The observed sound frequency (f).
- The velocity of the sound wave (v)
- The velocity of the sound source (v_s)
- The velocity of the object (*l*istener) (v_l).

If you listen carefully to the Doppler Effect, you will notice that the pitch increases when the observer and the source are moving closer to each other. But it decreases when the observer and the source are moving away from each other.

We can calculate the heard frequency using the following equation:

$$f = f_o \frac{v \pm v_l}{v \pm v_s}$$

Now we have different cases concerning the motion of both sound source (v_s) and object (listener) (v_l).



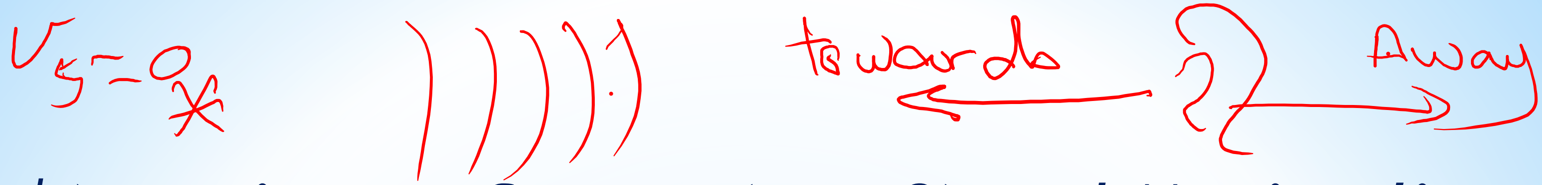
1st) *Moving Source and stationary listener ($v_l = 0$).*

(a) Moving toward the observer

$$f = f_o \frac{v}{v - v_s}$$

(b) Moving away from the source

$$f = f_o \frac{v}{v + v_s}$$



2^{nd}) stationary Source ($V_s = 0$) and Moving listener.

(a) Moving toward the sound source $$f = f_o \frac{v+v_l}{v}$$

(b) Moving away from the source $$f = f_o \frac{v-v_l}{v}$$

(3^{rd}) Both Sound Source and listener are Moving.

$$f = f_o \frac{v \pm v_l}{v \pm v_s}$$

(a) Moving toward each others

$$f = f_o \frac{v + v_l}{v - v_s}$$

(b) Moving Away from each others

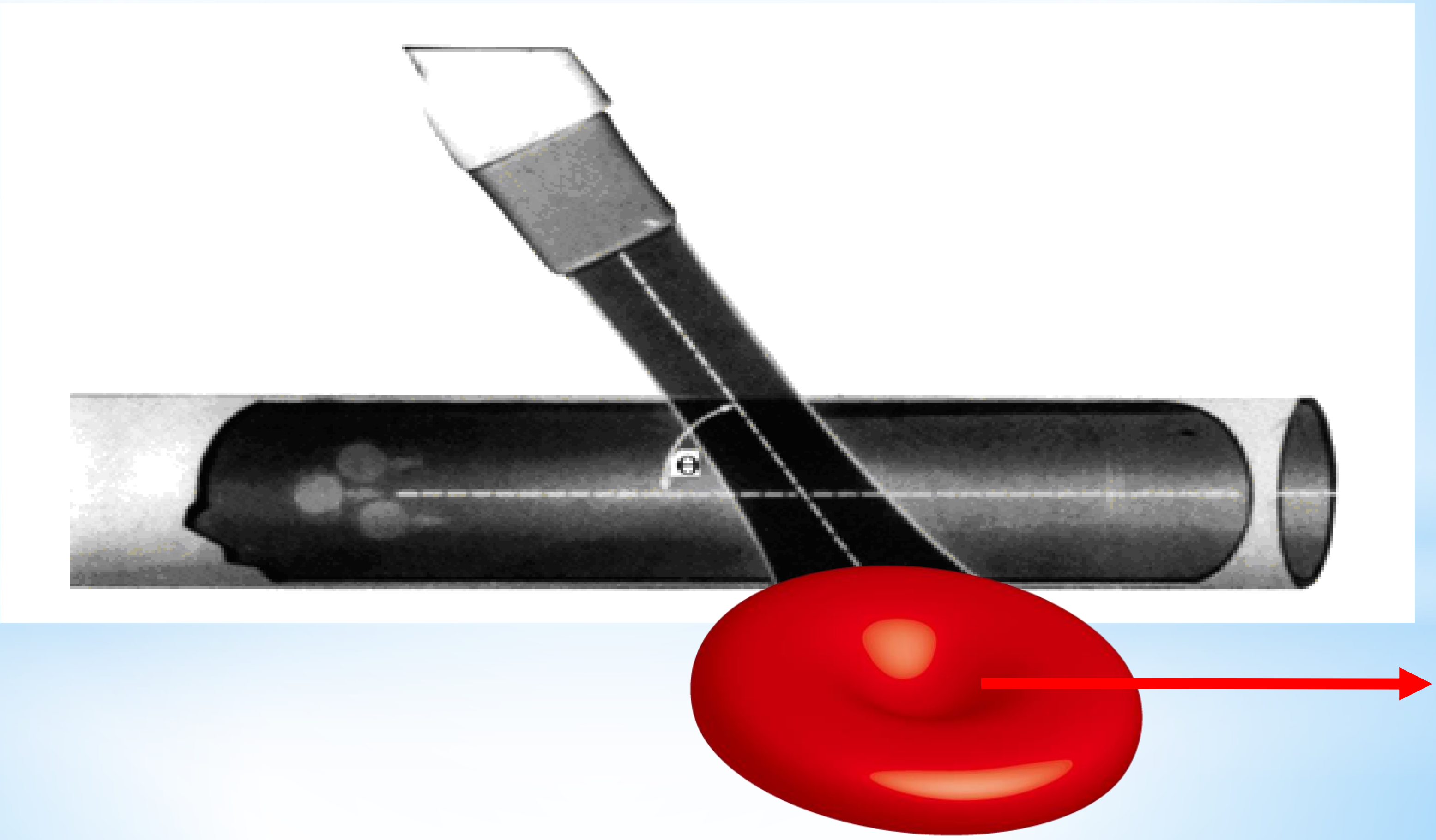
$$f = f_o \frac{v - v_l}{v + v_s}$$

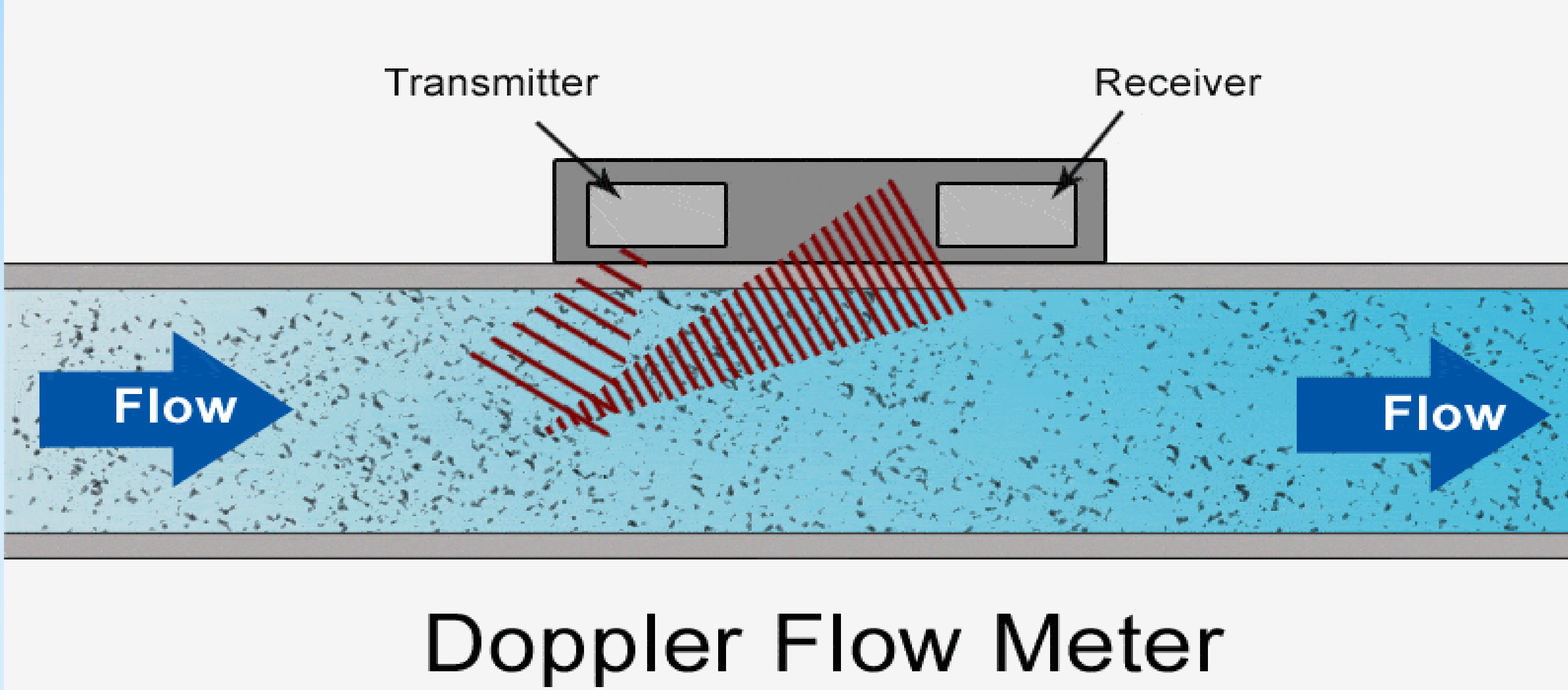
If there is an angle (θ) between the observer and the direction of the movement of the emit, **Doppler frequency shift can be calculated as:**

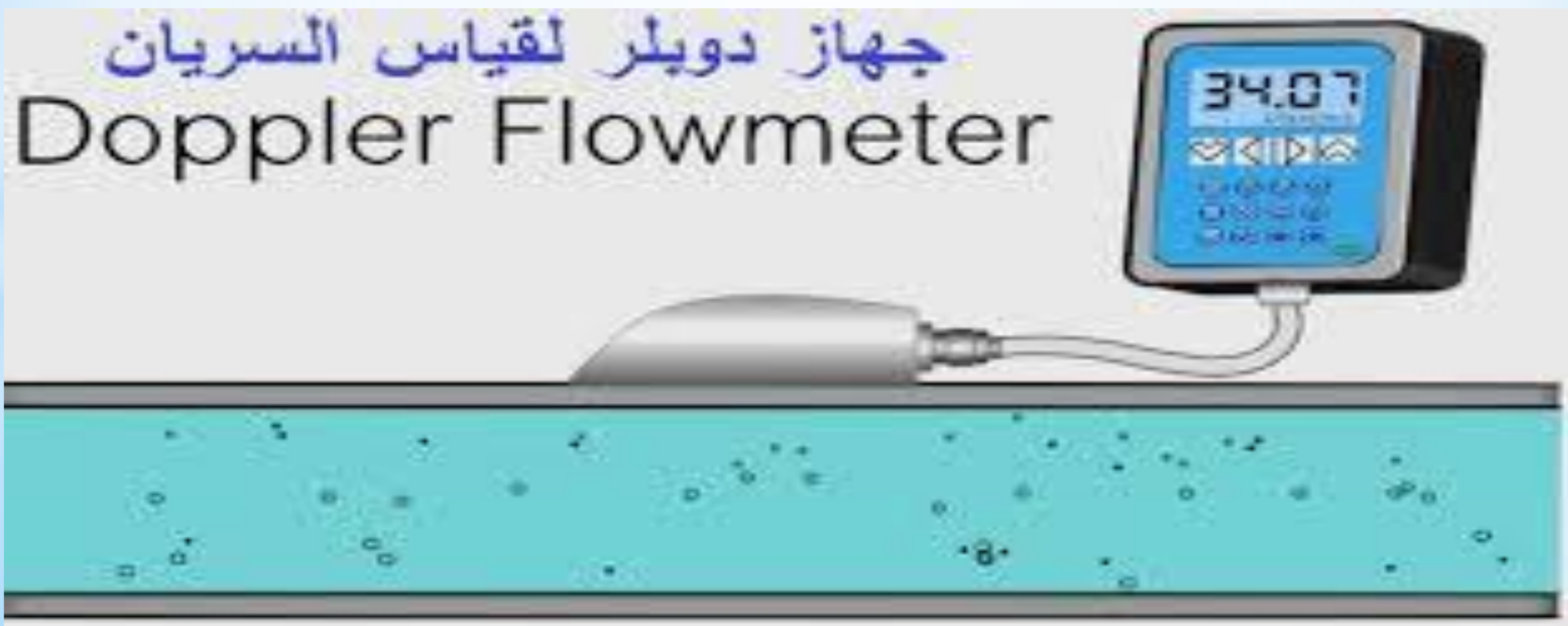
$$\Delta f = \frac{2 f_o}{v} v_l \cos\theta$$

Doppler Flow meter

The frequency shift can be used to measure blood flow rates by using a high-frequency sound source (ultrasound wave) on one side of the vessel and a detector on the other side.




Transmitter
Receiver
Flow
Flow
Doppler Flow Meter


جهاز دوبلر لقياس السريان
Doppler Flowmeter
34.07

The sound from the transmitter is reflected from red blood cells which are moving away from the source with a velocity v_l and detected at the receiver. If the angle of incidence (θ) is too small then, the frequency of the sound incident on the red blood cells moving away from the source is given by the following equation:

$$\Delta f = \frac{2f_o}{v} v_l \cos\theta$$

So,

$$v_l \; (v_{\text{blood}}) = v\Delta f / 2 f_o \cos\theta$$

Ex: A submarine (sub A) travels through water at a speed of 8 m/s, emitting a sonar wave at a frequency of 1400 Hz. The speed of sound in the water is 1533 m/s.

A second submarine (sub B) is moving at 9 m/s and is located such that both submarines are traveling directly toward one another.

(A) What frequency is detected by an observer riding on sub B as the subs approach (move towards) each other?

(B) The subs barely miss each other and pass. What frequency is detected by the observer riding on sub B as the subs recede (move Away) from each other?

$$f = f_o \frac{v \pm v_l}{v \pm v_s}$$

Ex: Two identical machines are positioned the same distance from a worker. The intensity of sound delivered by each machine at the location of the worker is 2×10^{-7} W/m².

Find the sound level heard by the worker

(A) when one machine is operating

(B) when both machines are operating.