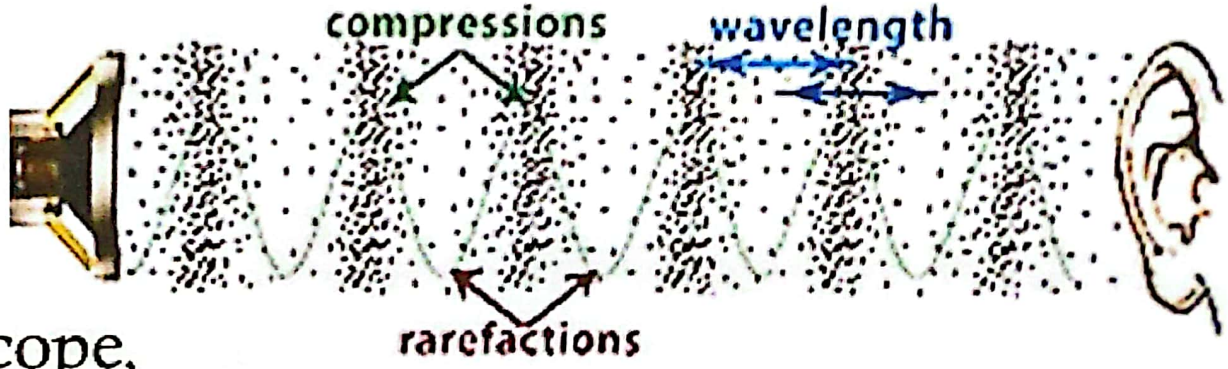
Acoustic and Ultrasound in Medicine

Sound is one of the most important ways to communicate by: speech, listening, and stimulation (music).

- A **sound wave**: is a mechanical disturbance in a gas, liquid, or solid that travels outward from the source with some definite velocity.

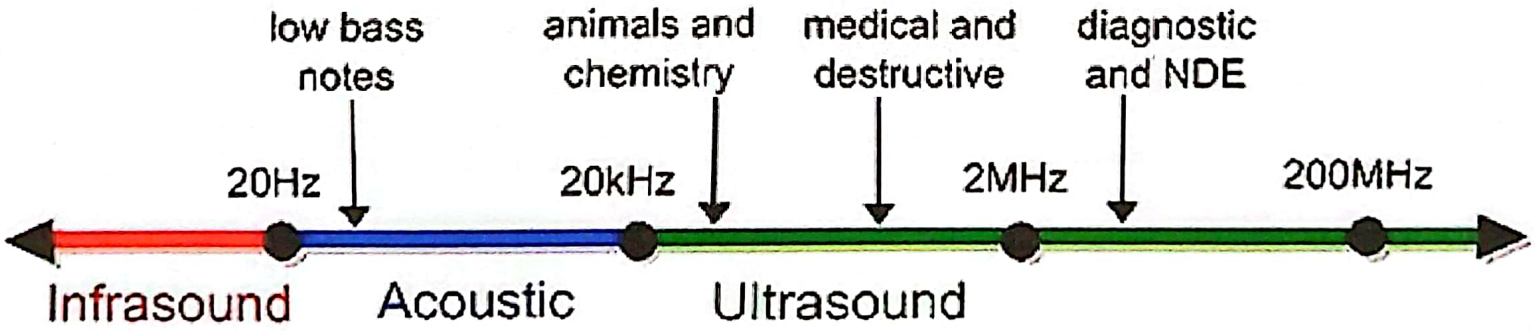
- The vibrations of loudspeaker back and forth in air cause local **increases** and **decreases** in pressure relative to *atmospheric pressure*.



- Sound can be used as a diagnostical tool:
  - **Resonation** > stethoscope,
  - **Transmission** and **reflection** > ultrasound imaging

General Properties of Sound

- Human sound system operates within a certain frequency range:
  - Range of human **voice**: 64 Hz to 205 Hz.
  - Range of human **ear** (the **audible sound**): 20Hz to 20 kHz.
  - Frequency *below* audible range: **Infrasound**
  - Frequency *above* audible range: **Ultrasound**

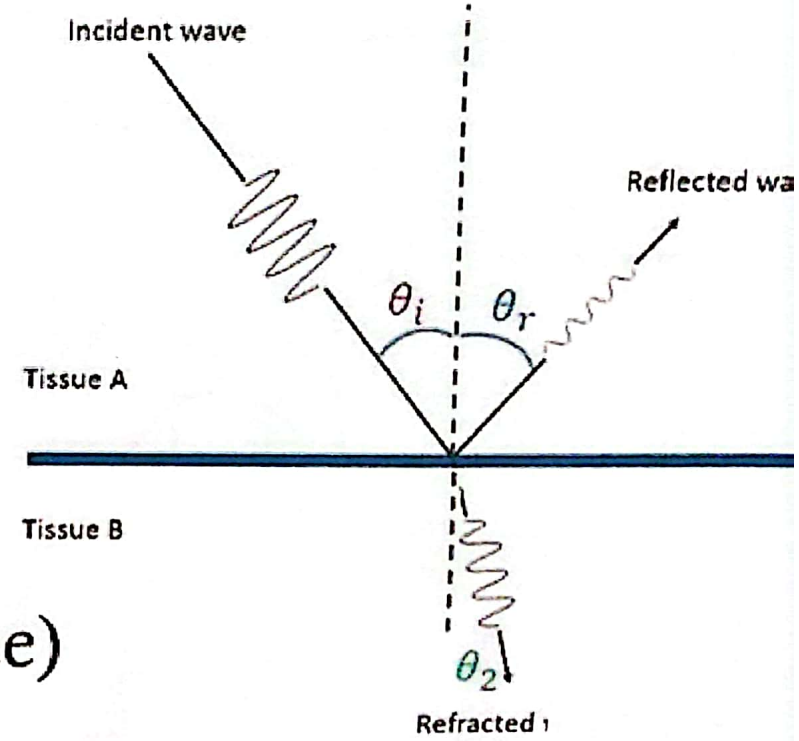


The relationship between the **frequency** of vibration f of the sound wave, the **wavelength** λ, and the **velocity** v of the sound wave is: $v = \lambda f$.

- The geometric laws involving the **reflection** and **refraction** are the same as for light.
- This means that:

$$\theta \text{ incident} = \theta \text{ reflected}$$

or $$\theta_i = \theta_r$$

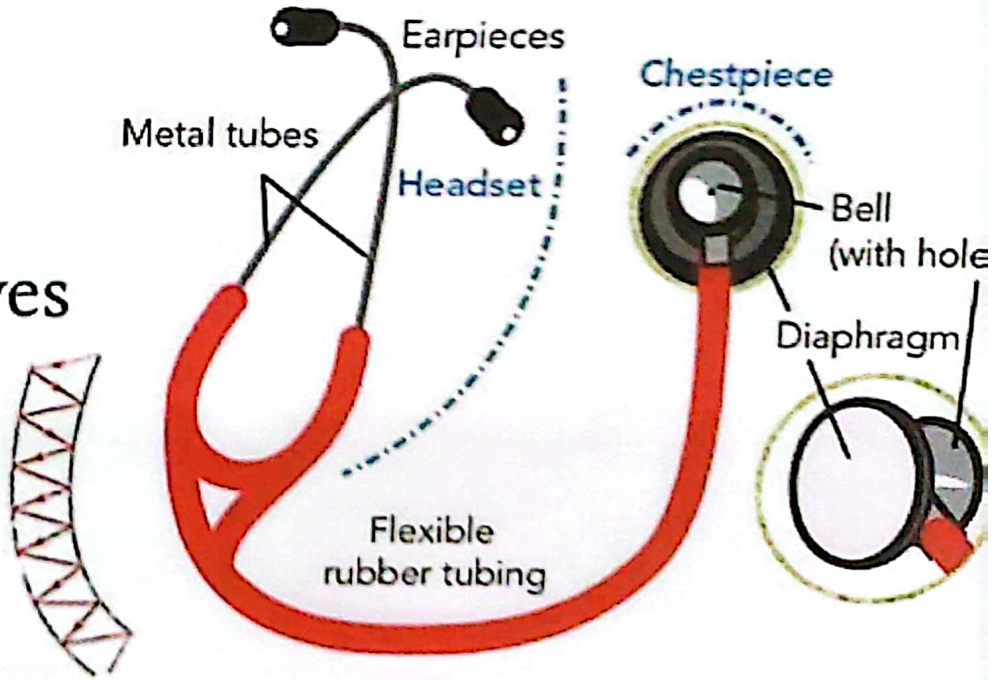


- The angle of the refracted sound wave θ_2 is determined by the velocities of sound in the two media v_1 (in A tissue) and v_2 (in B tissue) from the **Snell's law** equation:

$$\frac{\sin\theta_i}{v_1} = \frac{\sin\theta_2}{v_2}$$

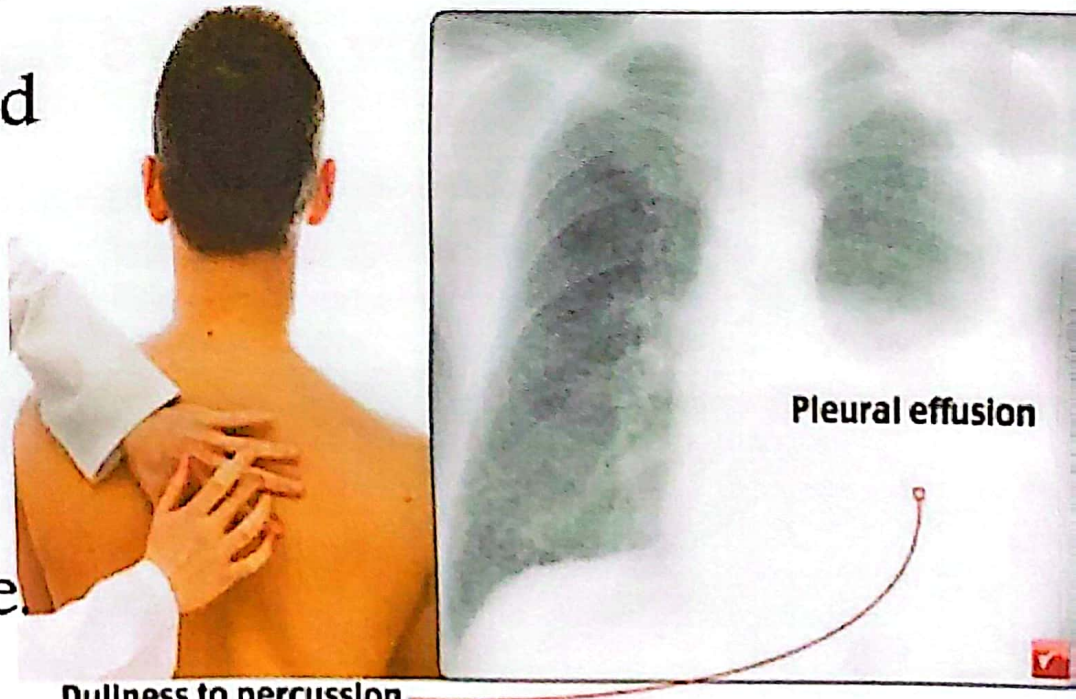
The Stethoscope

- Stethoscope is a simple hearing aid *permits a physician to* listen to sounds inside the body (*in the heart and lungs*).
  - The open bell is an impedance matcher *between the skin* and the air. (The skin behaves like a diaphragm).
  - A closed bell is a bell with a "diaphragm" of **known** resonant frequency.
- Because the vibrating object is attached to a tube, the sound waves are channeled in a specific direction, by process called **multiple reflection.**



Percussion in Medicine

- Percussion is an assessment technique which produces **sounds** by the examiner tapping on the patient's chest wall.
- Tapping on the chest wall produces sounds based on the amount of air in the lungs, so it helps to determine whether the underlying tissues are filled with air, fluid, or solid material.
- The quality of the sound:
  - Resonant = air filled space.
  - Dull = underlying solid tissue.

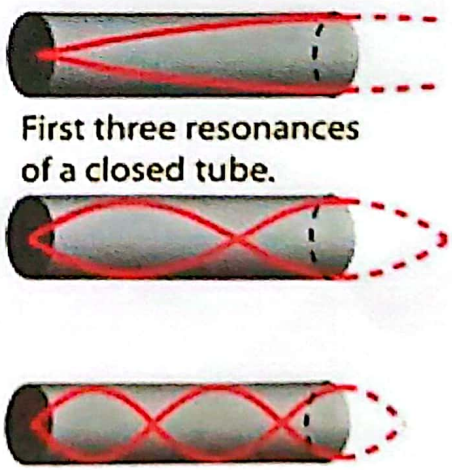


ysics of Speech

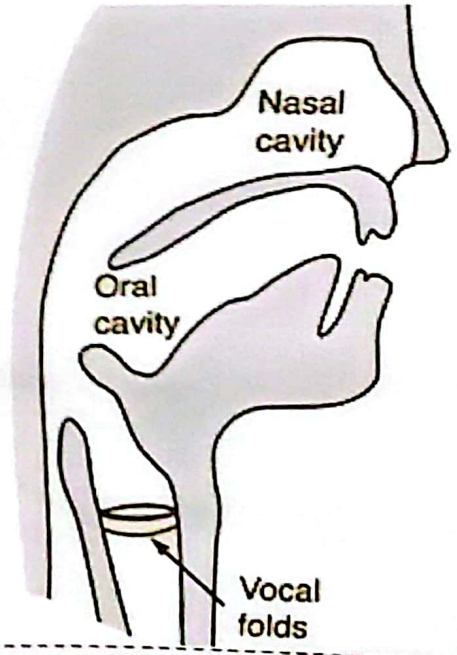
The speech mechanism in vowels can be described by a model that uses the physical properties of **tubes**.

A tube is an approximation of the shape of the **vocal tract**, from larynx to lips. It is a simple apparatus that can emit **harmonic frequencies**.

- The acoustic energy is supplied by the vocal cords, which are located at the lower, closed end of the apparatus.
- The tube acts as a **resonator** that "has an infinite number of resonances, located at frequencies given by **odd-quarter wavelength**.



First three resonances of a closed tube.



The **resonant frequencies** of a tube closed at one end are:

$$f_n = \frac{n\,c}{4\,L}$$

Where **n** is an integer, ***L*** is the length of the tube, and ***c*** is the speed of sound (about 35,000 cm/sec).

- As an **example**: if the average length of human tract from glottis to lips is L = 17.5cm, In this case:
  - 1st resonance frequency (F_1) occurs at 500 Hz,
  - the 2nd resonance frequency (F_2) at 1500 Hz,
  - the 3rd resonance frequency (F_3) at 2500 Hz, and so on.
- Another **example**: the average length in **females** is 14.1cm, give F_1=620.5 Hz, F_2=1861.7 Hz and F_3=3102.8 Hz

Ultrasound pictures of the body

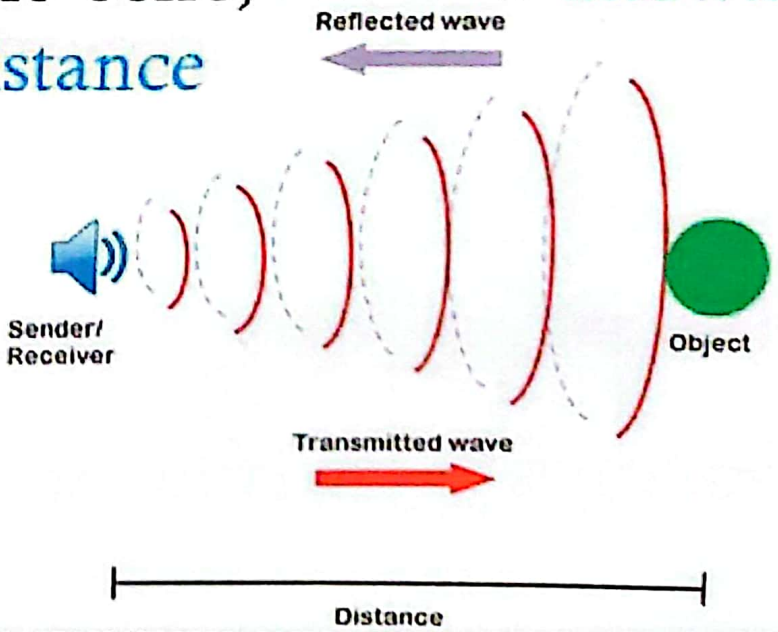
- Many of the applications of ultrasound in medicine are based on the principles of **sonar** (**So**und and **na**vigation and **r**inging):
- In sonar a sound wave pulse is *sent* out and is *reflected* from an object.
- From the time required to *receive* the echo, and the known velocity of sound in water >> the distance

to the object can be determined,

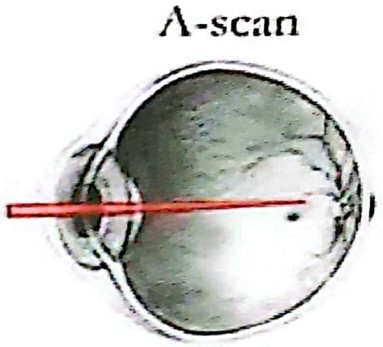
and the information on the distance

to the various structures or organs

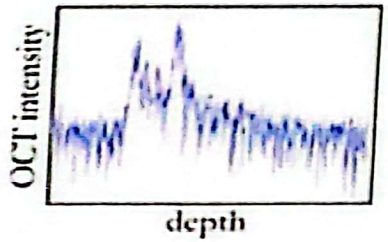
in the path of the ultrasound beam.



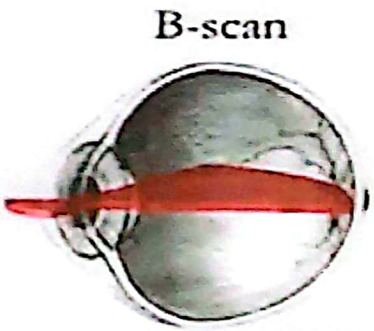
To obtain diagnostic information about the depth of structures in the body the procedure is called the **A Scan** method of ultrasound diagnosis. **A Scan** is used in:



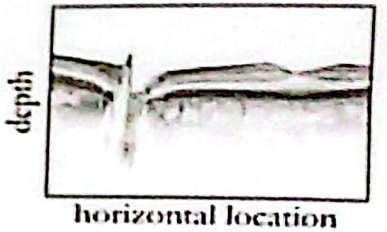
1. **Echoencephalography**: detection of the brain tumors.



2. **Ophthalmology**: Obtaining information in the diagnosis of eye diseases.

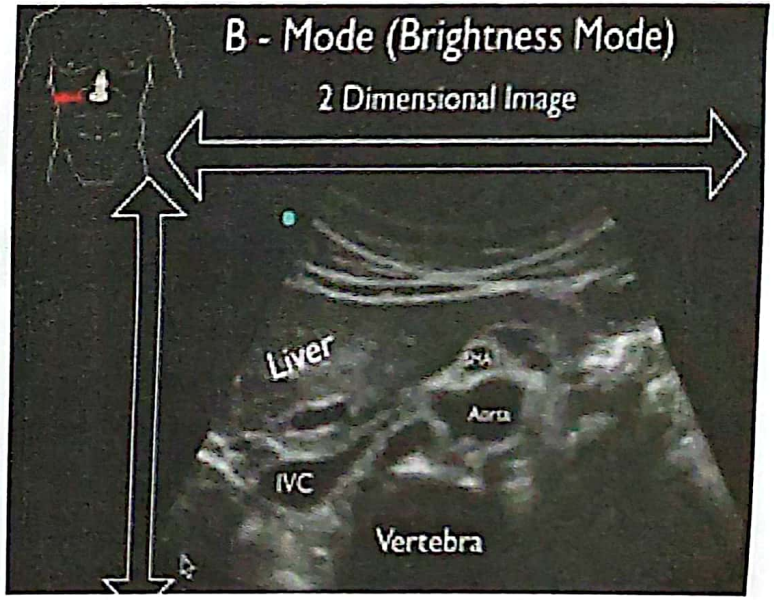


- **B Scans** is another method which used to obtain views of parts of the body.
  - It is provide information about the internal structure of the body.



Ultrasound to measure motion

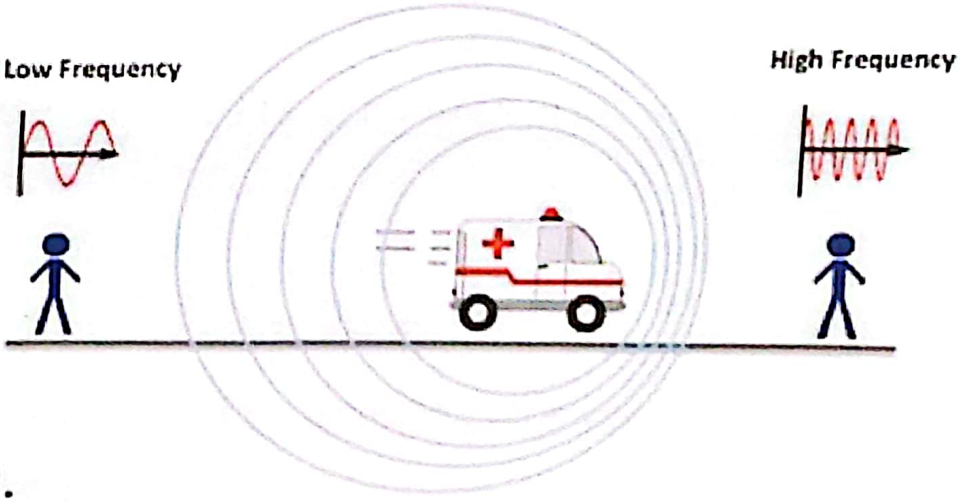
- Two methods are used to obtain information about **motion** in the body with ultrasound:



1. The **M** (motion) **Scan**: which is used to study motion such as that of the heart and the heart valves,
2. The **Doppler technique**, which is used to measure blood flow.

- The places where the heart can be probed are quite limited because of poor ultrasound transmission through lung tissue and bone.
- The echoes are very small signals due to weak reflection and the absorption of the sound by tissue.

- Physicists realized that a source of sound of frequency f_o has:
  - a **higher** pitch when it is moving toward a listener and a **lower** pitch when it is moving away from him.
  - a **higher** pitch when the listener is moving toward the source than when he is moving away from it.
- The frequency change is called the **Doppler Shift**.
- The **Doppler effect** (or the Doppler shift): is the *change* in frequency or wavelength of a wave for a listener who is moving relative to the wave source.



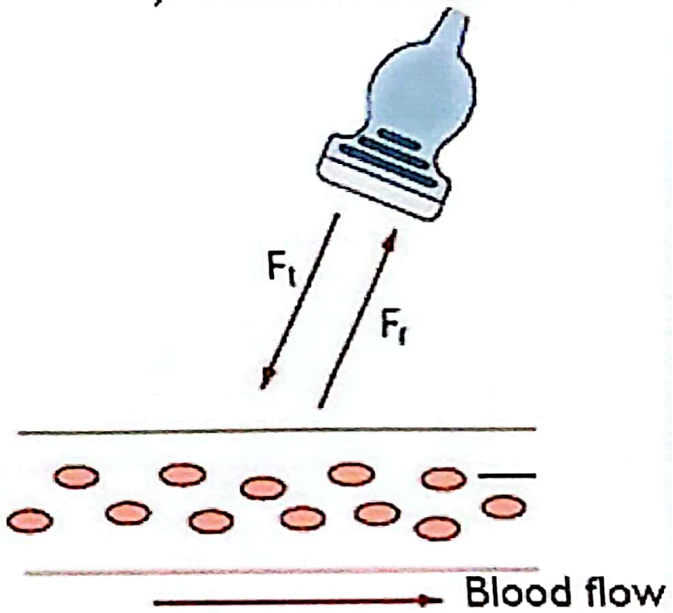
The Doppler effect applied to diagnostic ultrasound

- The Doppler effect can be used to study **blood flow** to determine: presence or absence of blood flow, direction of it, and velocity of flowing.

- The transducer (Ultrasound generators)

  acts as both a transmitter and receiver

  of Doppler ultrasound.

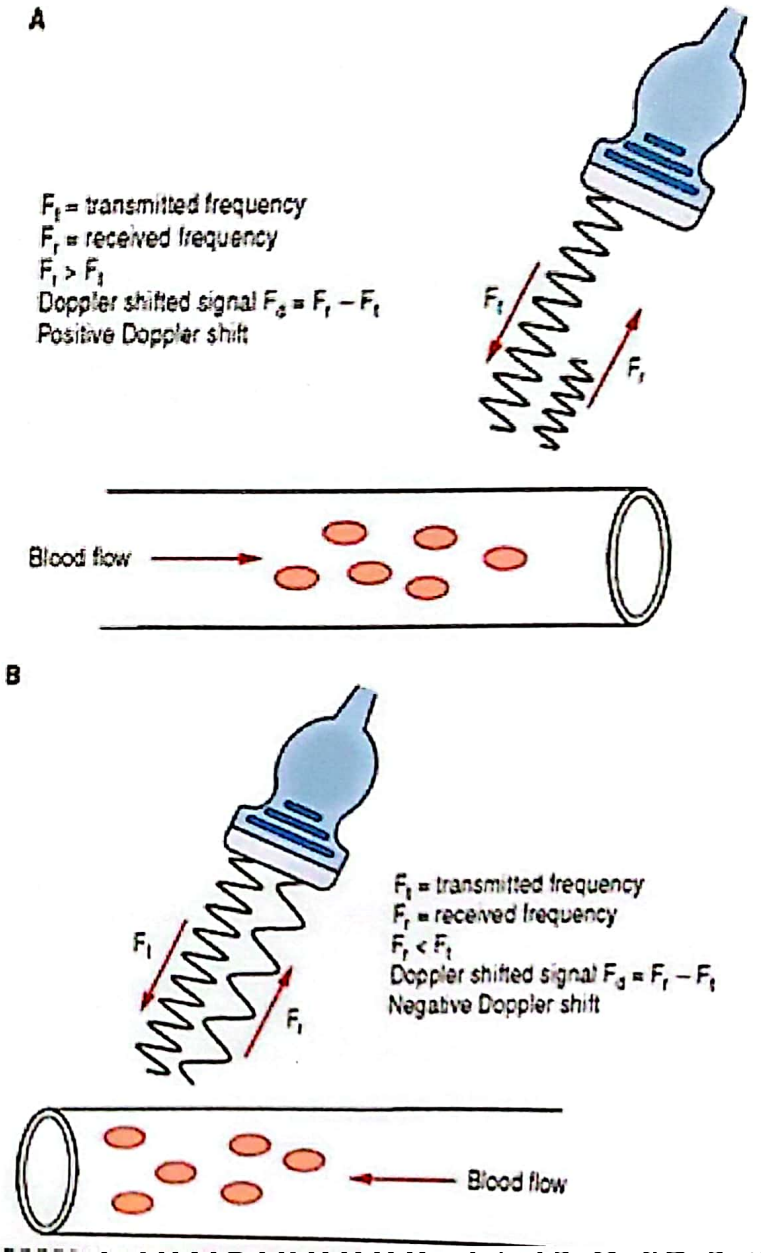


- The returning backscattered echoes from blood are *detected* by the transducer.

- These backscattered signals (F_r) are then processed by the machine to detect any frequency shifts by **comparing** these signals to the transmitted Doppler signals (F_t).

- If the relative direction of the blood flow with respect to the Doppler beam is **towards** the transducer. The Doppler shifted signal produce positive Doppler shifted signal.

- If the blood flow is moving **away** from the Doppler beam and the transducer. The Doppler shifted signal produces a negative Doppler shifted signal.



- The detector receives a backscattered signal that has undergone a double Doppler Shift.
- When the blood is moving at an angle from the direction of the sound waves, the frequency change is:

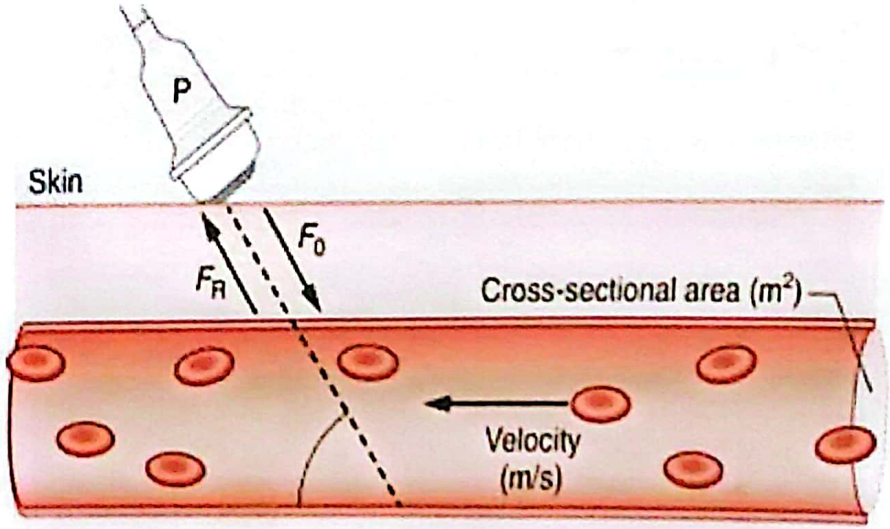
$$f_R = \frac{2\, f_o V}{v} \cos\theta$$

where f_o: is the frequency of the initial ultrasonic wave,

V: is the velocity of the blood,

v: is the velocity of sound,

and θ: is the angle between V and v.



The Doppler Effect is also used to *detect motion of* the **fetal heart**, **umbilical cord**, and **placenta** *in order to* establish fetal life (during the 12 to 20 week of *gestation*).

When f_o is incident upon the fetal heart, the reflected sound unreliable.

It is shifted to frequencies slightly **higher** than f_o when the fetal heart is moving toward the source of sound.

and slightly **lower** than f_o when the fetal heart is moving away from it.

Variations in the frequency give the fetal heart rate.