Ultrasound Machine

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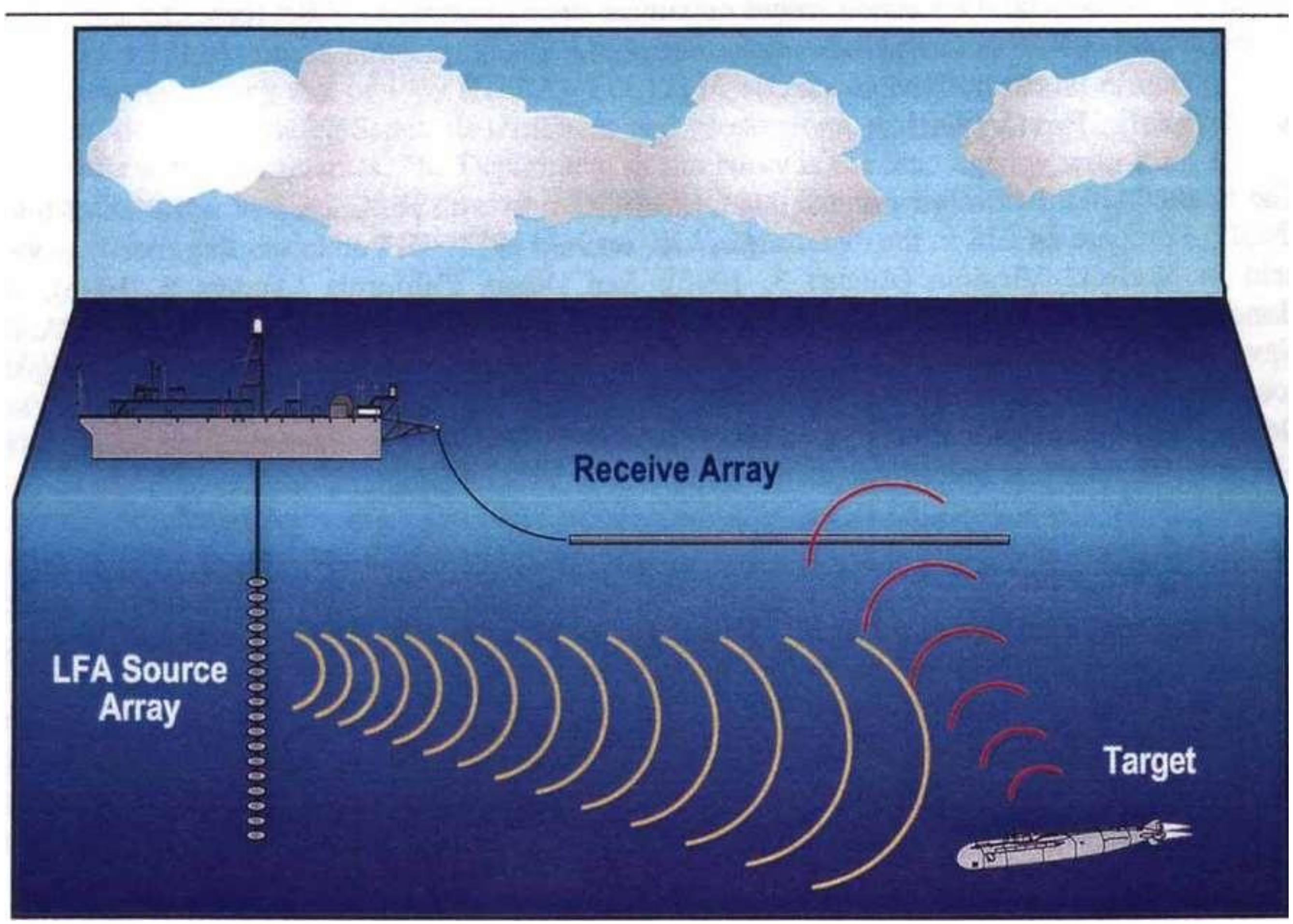
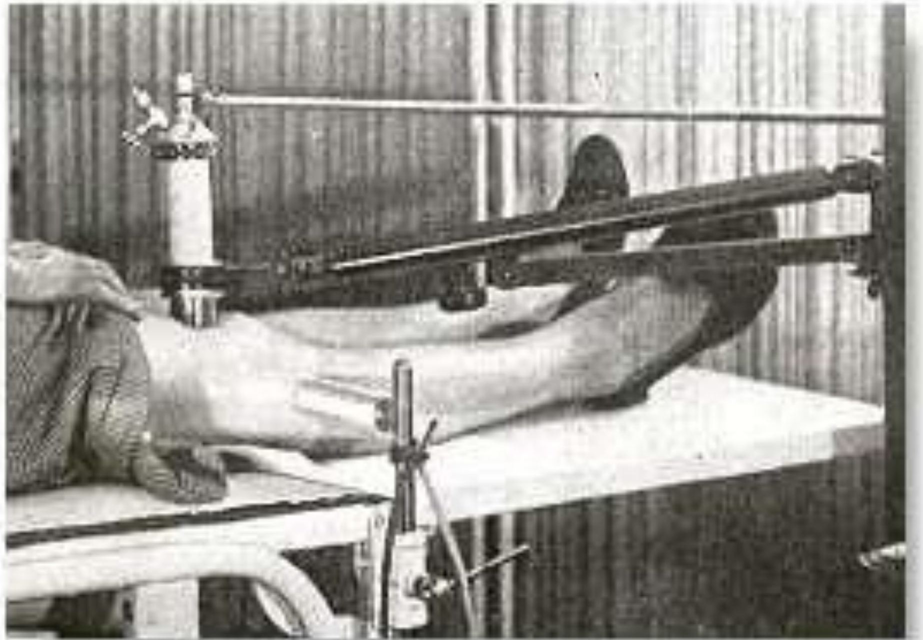
Sound Waves and Ultrasound

History

- First successful application – SONAR in world war 2 (**S**ound **N**avigation **A**nd **R**anging)



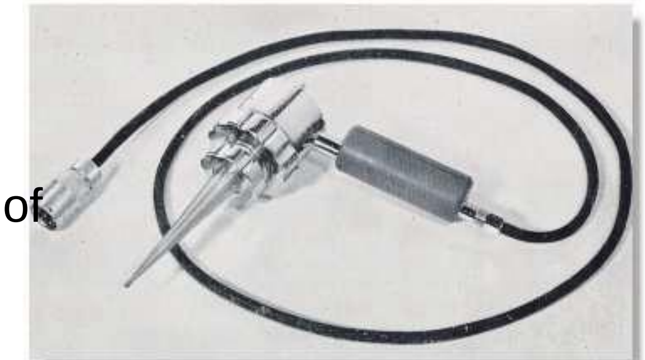
Successful medical application – 1940s



Uses of ultrasonic energy in the 1940s. Left, in gastric ulcers. Right, in arthritis

Ultrasonic therapy generator, the "Medi-Sonar" in the 1950s.

A British ultrasonic apparatus for the treatment of Meniere's disease in the late 1950s



The Present

Approximate Frequency Of Ultrasound in Various Body Organs

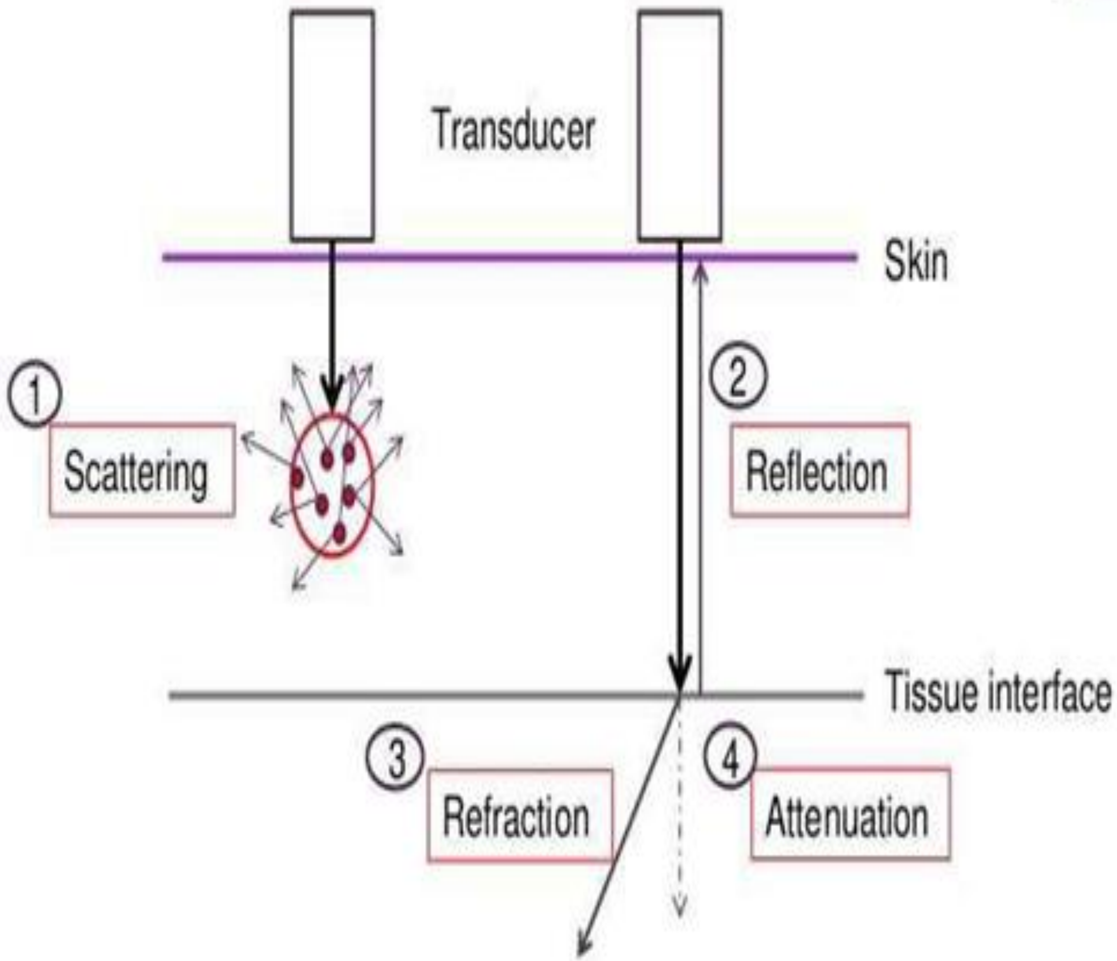
Material	Velocity (m/s)
Fat	1,475
Brain	1,560
Liver	1,570
Kidney	1,560
Spleen	1,570
Blood	1,570
Muscles	1,580
Lens of Eye	1.620
Bone	3,500-4,800
Soft Tissue (Mean value)	1,540
Air	3,30

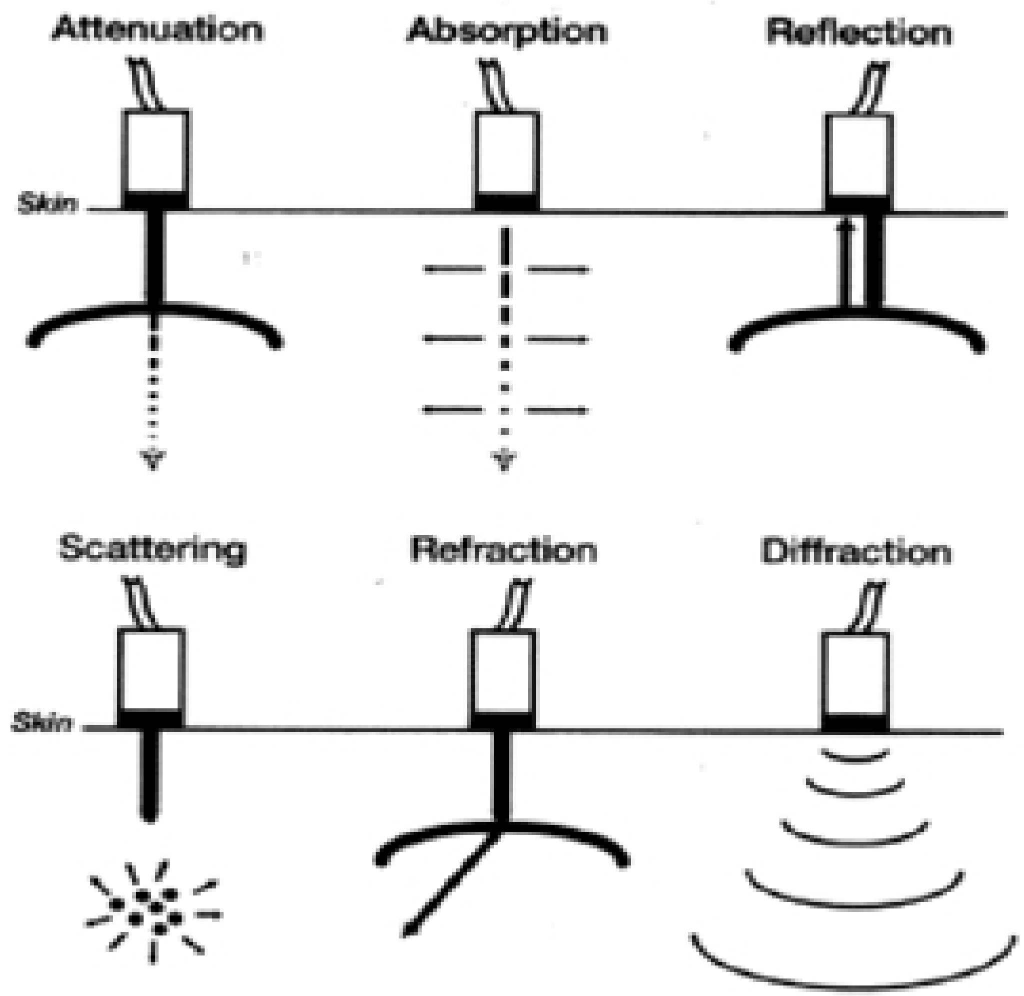
PRINCIPLE OF ULTRASOUND

- Ultrasound waves are created by a vibrating crystal within a ceramic probe.
- Waves travel through the tissue and are partly reflected at each tissue interface.
- "Piezoelectric " principle- electric current causes crystal to vibrate, returning waves create electric current.

- Following phenomenon occur when ultrasound propagates through matter:
    - Reflection
    - Refraction
    - Diffraction
    - Attenuation
    - Scattering

Interactions of Ultrasound with tissue





ULTRASONOGRAPHY

- Ultrasonography or diagnostic sonography is an ultrasound based diagnostic imaging technique used for visualizing internal body structures.

Events occurs in Ultrasonography

- ☐ The sound waves are sent through body tissues with a device called a transducer.
- ☐ The transducer is placed directly on top of the skin, which has a gel applied to the surface.
- ☐ The sound waves that are sent by the transducer into the body and hit a boundary of organs
- ☐ Some of the sound waves get reflected back to the probe, while some travel on further until they reach another boundary and get reflected.
- ☐ The machine calculates the distance from the probe to the tissue or organ (boundaries) and the time of the each echo's return (usually on the order of millionths of a second).

Cont…

- The machine displays the distances and intensities of the echoes on the screen, forming a two dimensional image.
- The echo images are then recorded on a plane film and can also be recorded on videotape.
- In ultrasound millions of pulses and echoes are sent and received each second. The probe can be moved along the surface of the body and angled to obtain various views.
- After the ultrasound, the gel is wiped off.

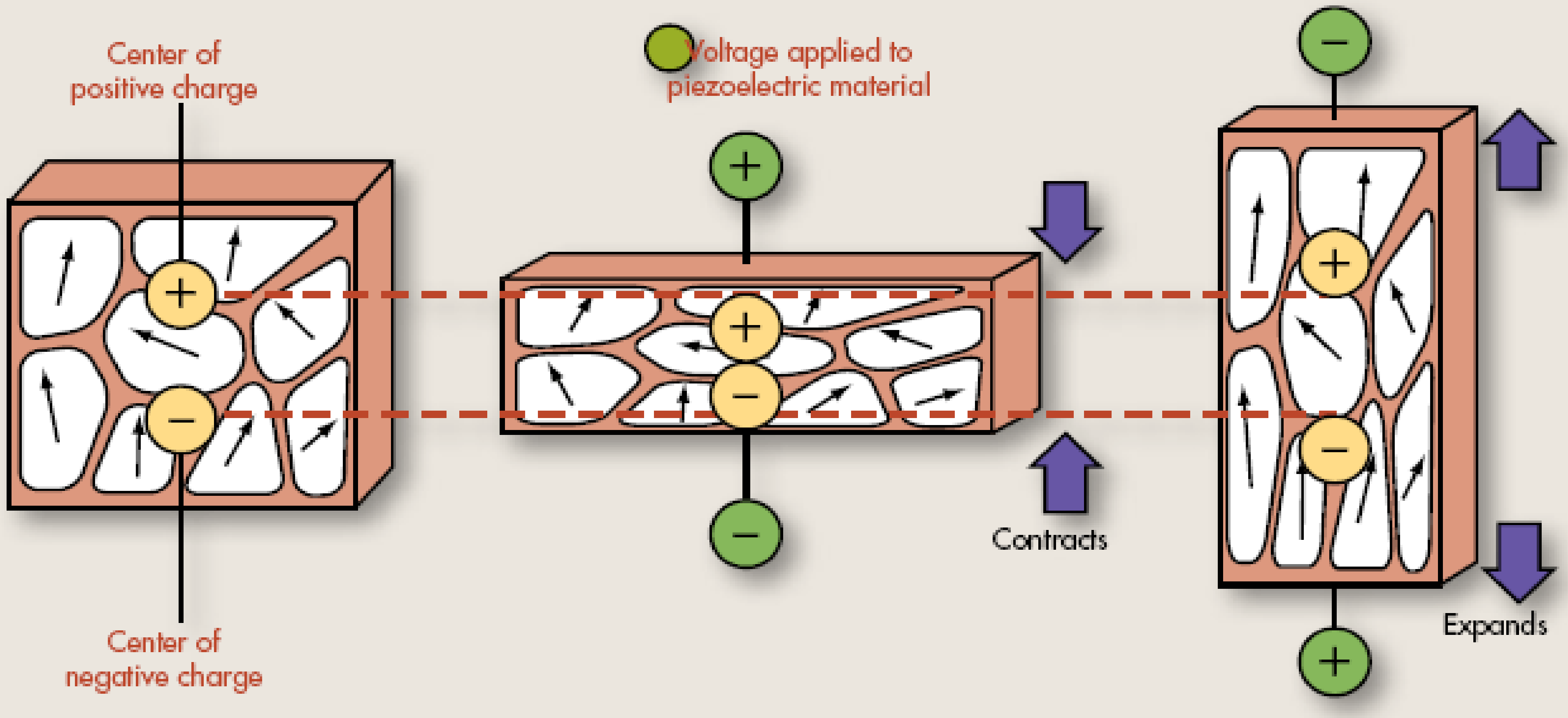
The Piezoelectric Effect

- piezoelectric means pressure electricity
- Ultrasound waves are produced using the piezoelectric effect.
- When a potential difference (p.d) is applied across certain crystals (piezoelectric) the crystals themselves deform and contract a little.
- If the p.d. applied is alternating then the crystal vibrates at the same frequency and sends out ultrasonic waves.
- For ultrasound - lead zirconate titanate (PZT) crystals are used.

  This process also works in reverse. The piezoelectric crystal acts a receiver of ultrasound by converting sound waves to alternating voltages and as a transmitter by converting alternating voltages to sound waves.

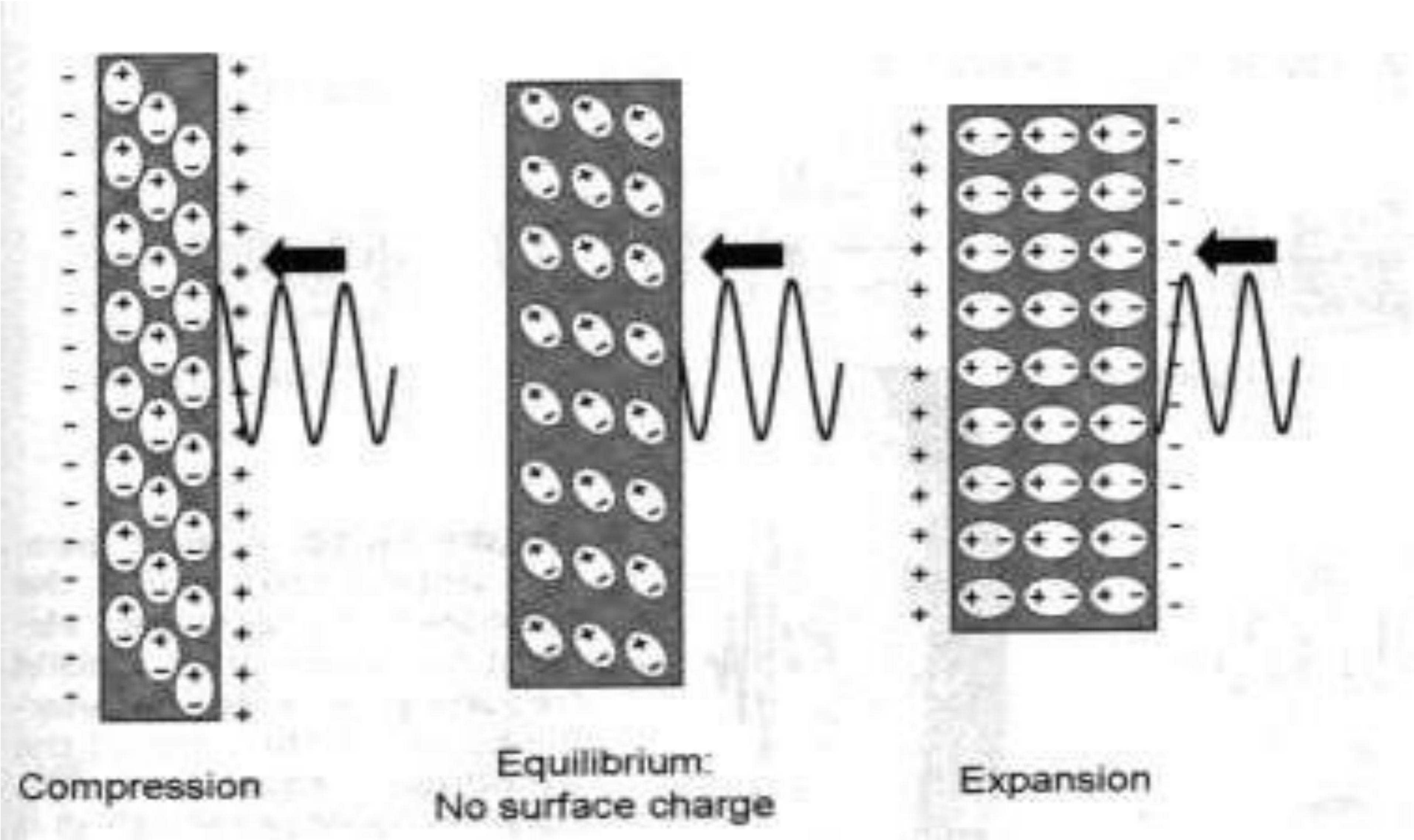
Cont…

Discovered by Pierre and Jacques Curie in 1880.



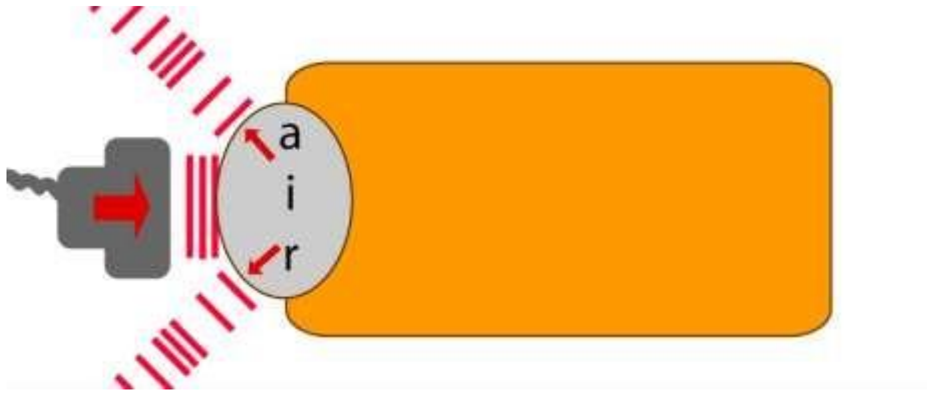
1. The piezoelectric effect causes crystal materials like quartz to generate an electric charge when the crystal material is compressed, twisted, or pulled. The reverse also is true, as the crystal material compresses or expands when an electric voltage is applied.

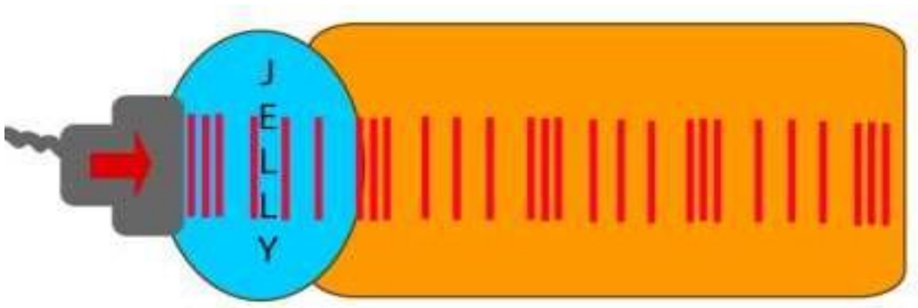
Piezoelectric Effect



Couplant

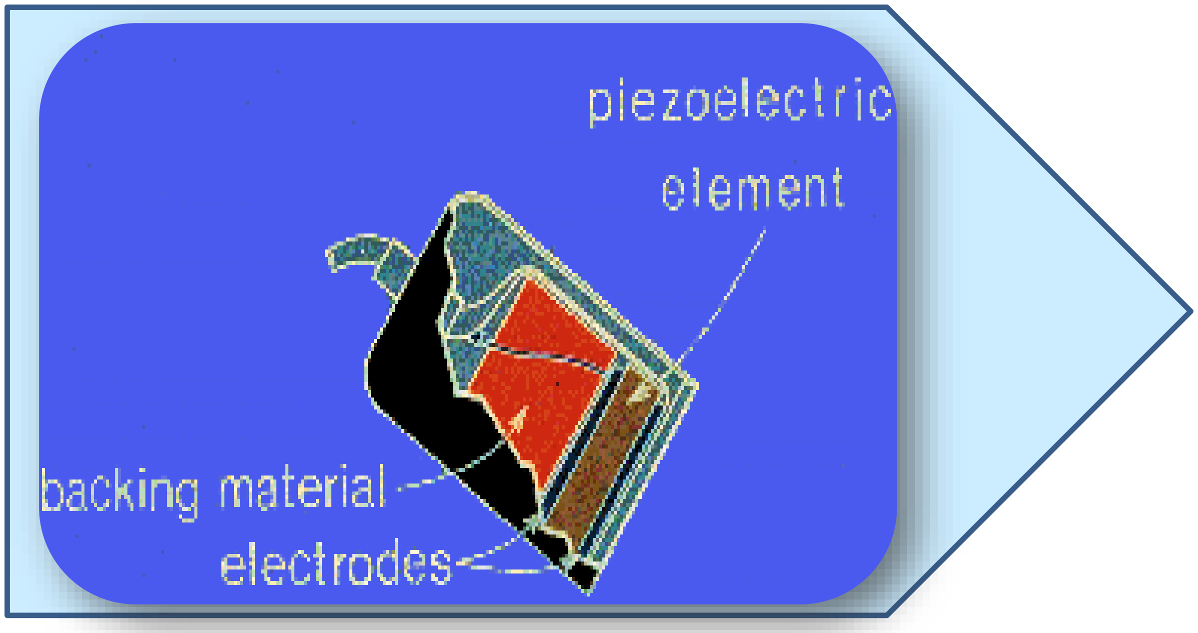
- Material (usually liquid jelly) that facilitates the transmission of ultrasonic energy from the transducer into the test specimen.
- Necessary to overcome the acoustic impedance mismatch between air and solids.





Piezoelectric Element

- The active element is basically a piece of polarized material - a **piezoelectric ceramic** sandwiched between electrodes
- The piezoelectric element converts electrical signals into mechanical vibrations (transmit mode) and mechanical vibrations into electrical signals (receive mode).

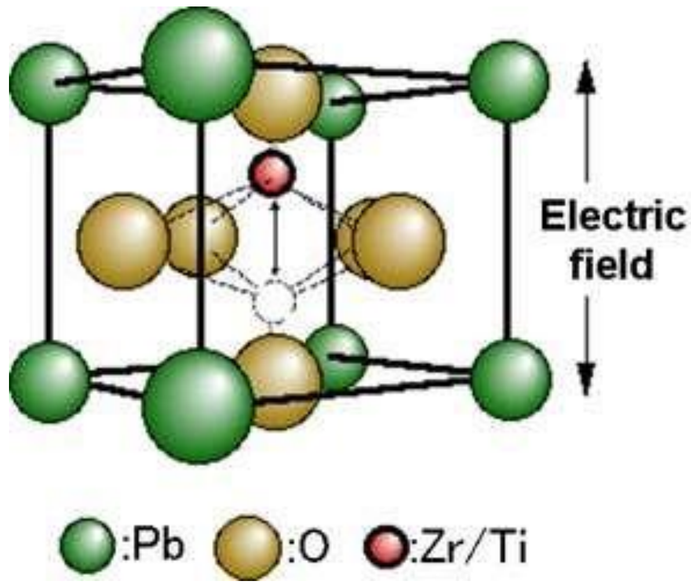


Transducer

Piezoelectric materials

- Natural – Quartz
- Artificial
  - Ferroelectrics
  - Ceramic
    - barium titanate
    - PZT (lead zirconate titanate)

Advantage: they can be formed into different shapes



Acoustic Impedance, Z

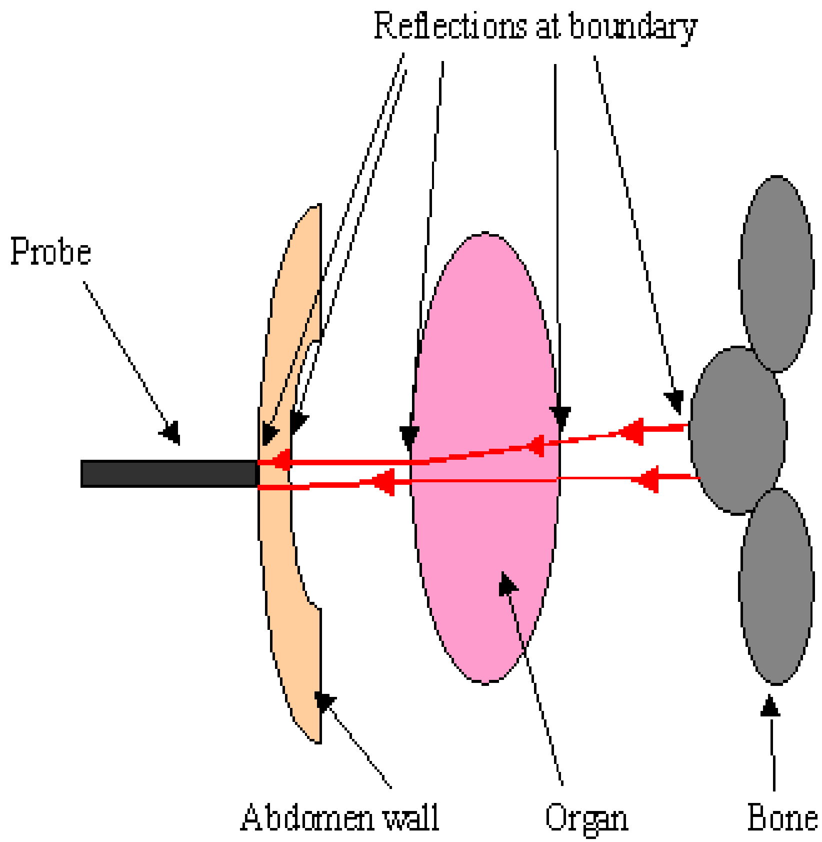
When an ultrasound wave meets a boundary between two different materials some of it is refracted and some is reflected. The reflected wave is detected by the ultrasound scanner and forms the image. The proportion of the incident wave that is reflected depends on the change in the acoustic impedance, Z.

Acoustic Impedance, Z of a medium is defined as:

$$Z = \rho c$$

Where ρ = the density of the material, kgm^{-3}

c = speed of sound in that material, ms^{-1}



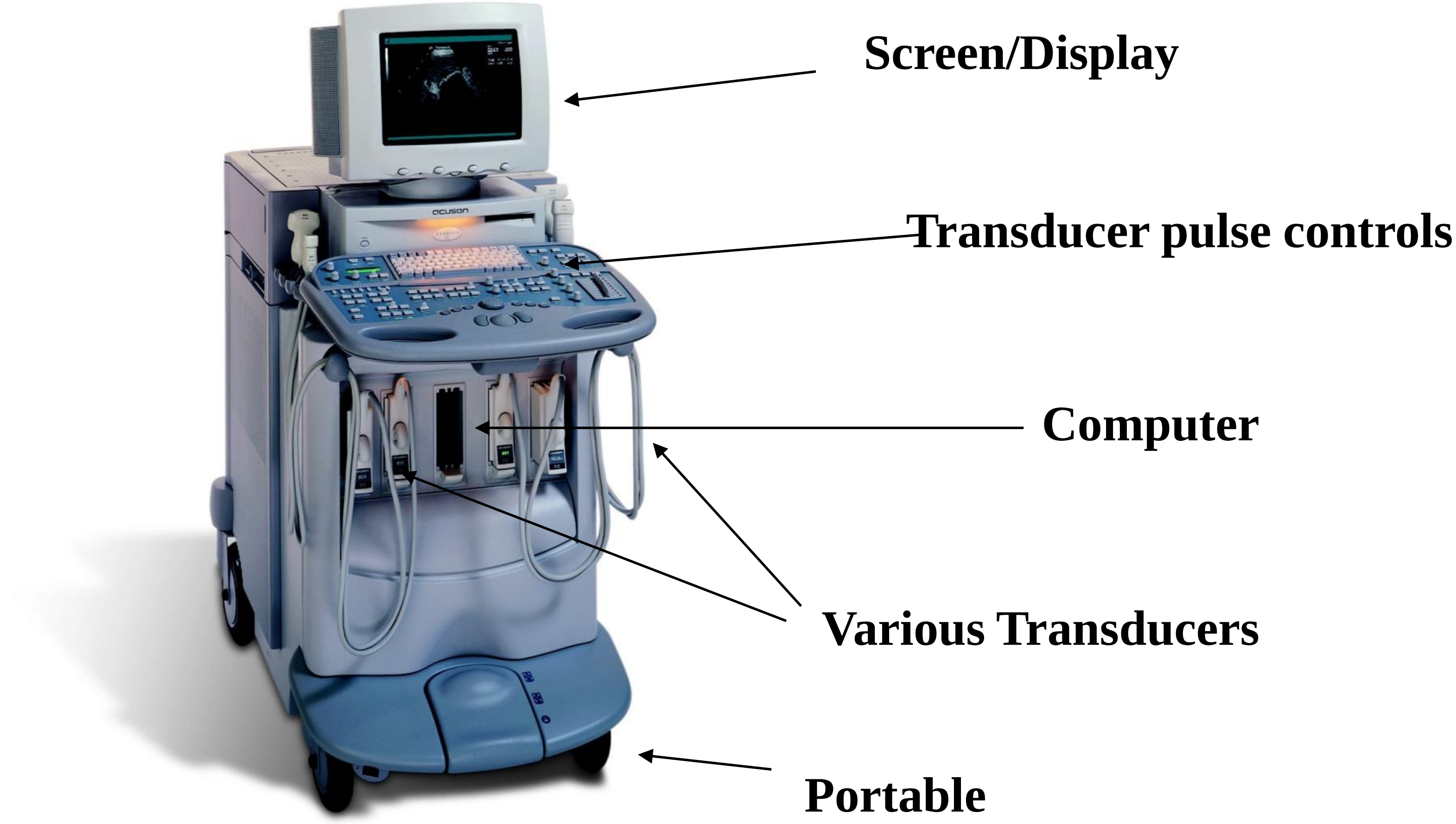
Impedance Matching Gel

When ultrasound passes through two very different materials the majority of it is reflected. This happens between air and the body, meaning that most ultrasound waves never enter the body.

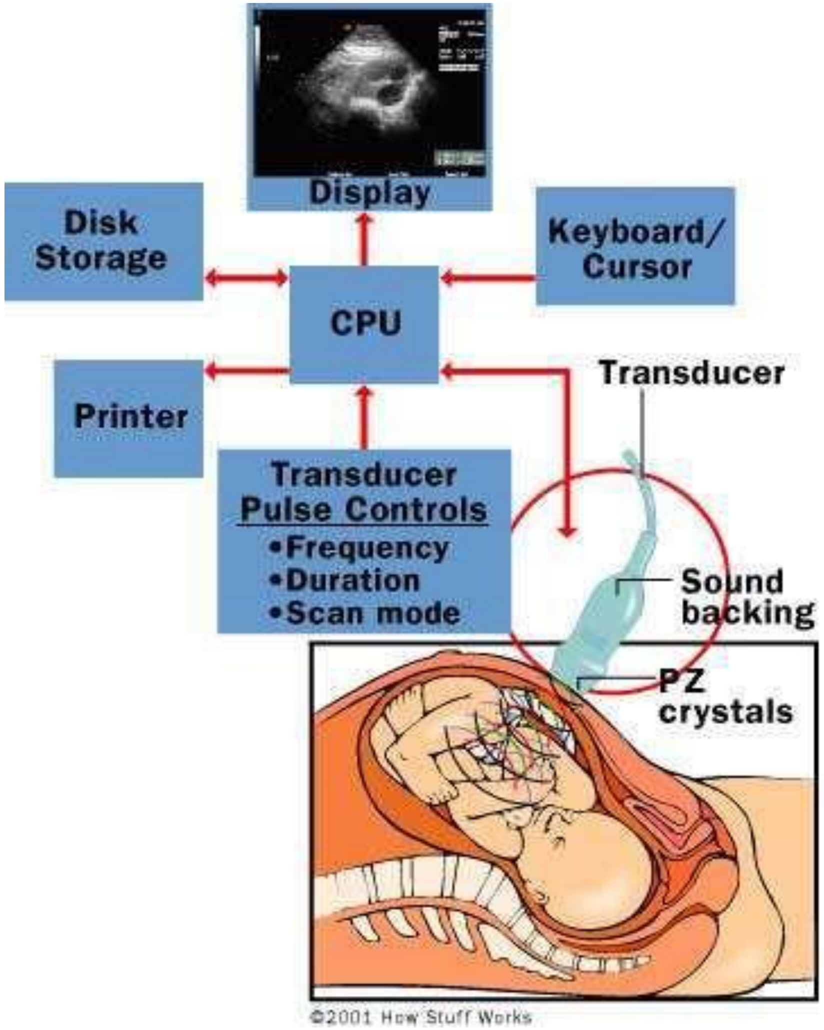
To prevent this large difference in impedance a coupling medium (gel) is used between the air and the skin. The need to match up similar impedances to ensure the waves pass through the body is known as impedance matching.

Ultrasound Equipment

Ultrasound Equipment



Block Diagram



Ultrasound Machine parts

- Transducer Probes
- Central Processing Unit (CPU)
- Transducer Pulse Controls: controls settings for the probe
- Display
- Keyboard/Cursor
- Disk Storage Device
- Printer

The Ultrasound Machine

A basic ultrasound machine has the following parts:

1. **Transducer probe** - probe that sends and receives the sound waves
2. **Central processing unit (CPU)** - CPU does all of the calculations and contains the electrical power supplies for itself and the transducer probe
3. **Transducer pulse controls** - changes the amplitude, frequency and duration of the pulses emitted from the transducer probe
4. **Display** - displays the image from the ultrasound data processed by the CPU
5. **Keyboard/cursor** - inputs data and takes measurements from the display
6. **Disk storage device** (hard, floppy, CD) - stores the acquired images
7. **Printer** - prints the image from the displayed data

1- Transducer Probe

- Based upon the pulse-echo principle occurring with ultrasound piezoelectric crystals, ultrasound transducers convert:
  - Electricity into sound = pulse
  - Sound into electricity = echo
- It is the main part of the ultrasound machine. The transducer probe makes the sound waves and receives the echoes.
- Piezoelectric Crystal- reversible used to both excite and detect ultrasound waves.

Cont...

- In the probe, there are one or more quartz crystals called Piezoelectric crystals.
- When an electric current is applied to these crystals, they change shape rapidly. The rapid shape changes, or vibrations, of the crystals produce sound waves.
- The same crystals can be used to send and receive sound waves.
- Multiple-element probes have the advantage that is especially important for cardiac ultrasound.

Cont…

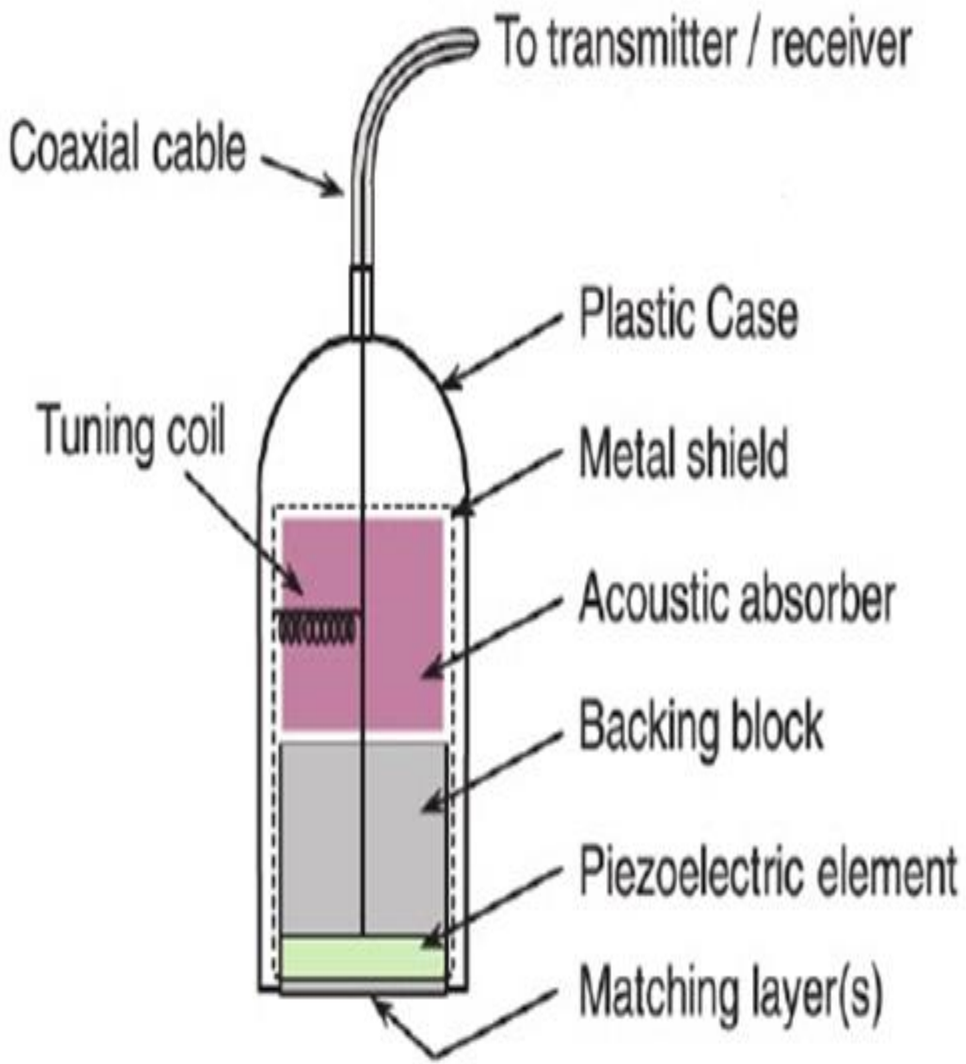
- Piezoelectrical transducers are used to achieve the high-frequency ultrasound energy needed for imaging and therapy.
- These are suitably cut crystals, which change shape under the influence of an electric charge.
- Many types of crystal can be used but the most favored are *quartz, which occurs naturally, and some synthetic ceramic materials such as* ***barium titanate and lead zirconate titanate (PZT).***

Cont…

- These crystals deform when subjected to a varying potential difference
- The reverse of the piezoelectric effect converts the energy back to its original form.
- The crystal must be cut to suitable dimensions – the most important being the thickness – so that it will resonate at the chosen frequency and so achieve maximum vibration.

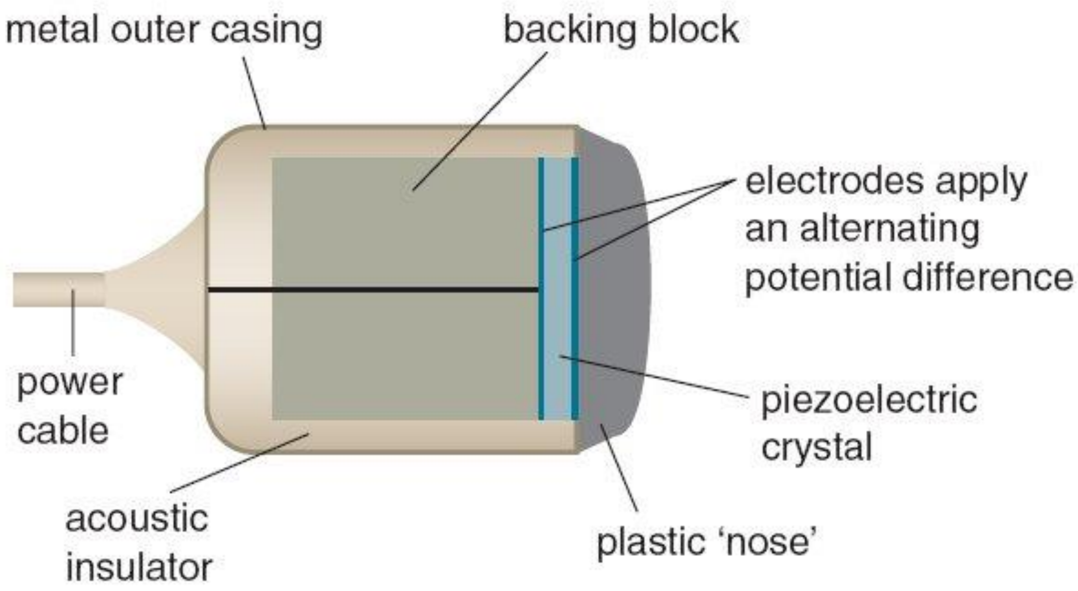
Transducer - Parts

- A simple single-element, plane-piston source transducer has major components including the:
  - Piezoelectric element
  - Metal shield
  - Transmitter/receiver
  - Acoustic absorber
  - Backing block
  - Matching layer
  - Tuning coil
  - Coaxial cable
  - Plastic case



Transducer shape and size

The curved faceplate shapes the ultrasound waves into a narrow beam.



Transducer probes come in many shapes and sizes.

The shape of the probe determines its field of view, and the frequency of emitted sound waves (controlled by the tuning device) determines how deep the sound waves penetrate and the resolution of the image. The ultrasound is pulsed. There must be a pause to allow the reflected wave to be detected.

TRANSDUCER DESIGN:

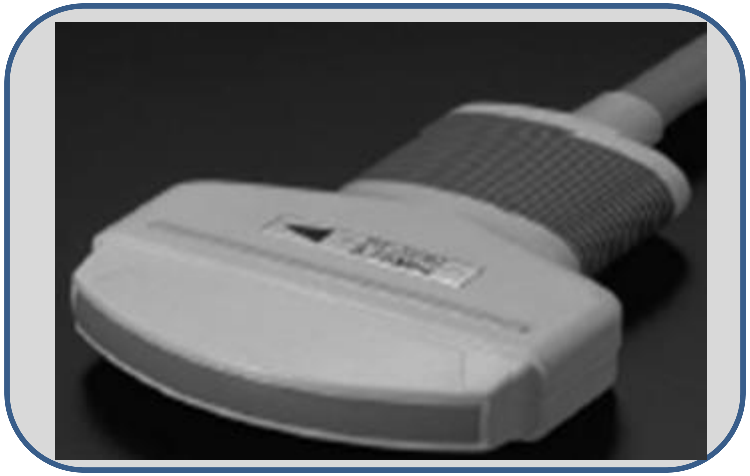
Size, design and frequency depend upon the examination

SELECTION OF TRANSDUCER

- Superficial vessels and organs within 1 to 3cms depth and intra operative imaging –
  - 7.5 to 15 Hz
- Deeper structures in abdomen and pelvis within 12 to 15cms –
  - 2.25 to 3.5Hz

Electronics Transducer

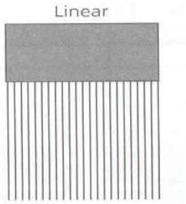
- Curved Array
  - — crystals are placed parallel or in concentric rings
  - — transducer face is curved
  - — produces sector or pie-shaped image



- Linear Array
  - — crystals are placed parallel
  - — transducer face is flat
  - — produces rectangular image

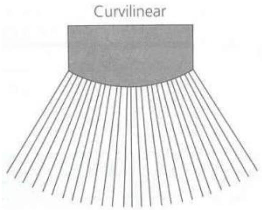
Transducers

Linear array: *linear probe*

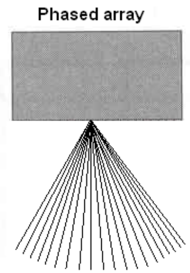


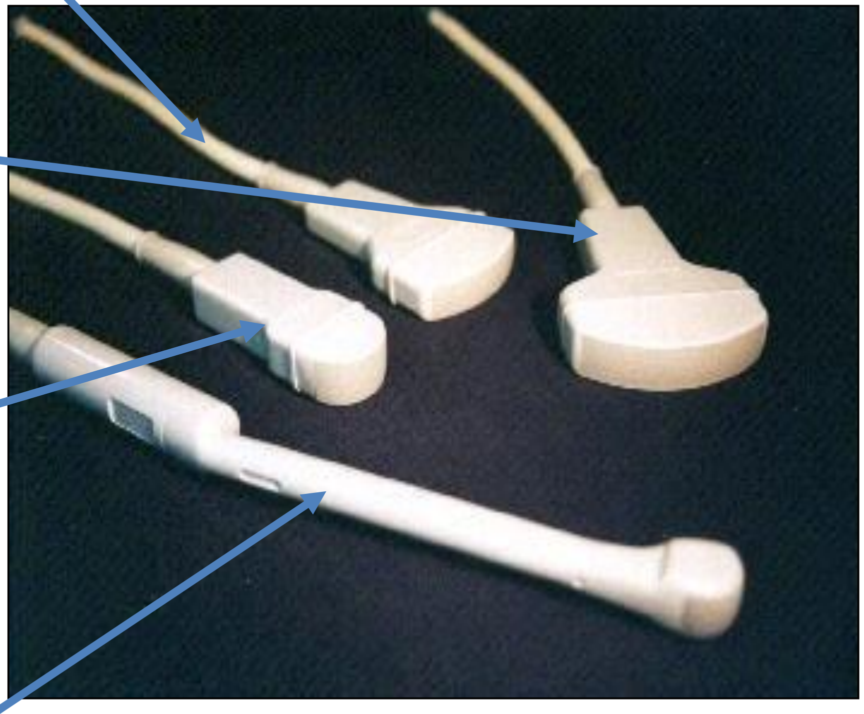
Linear array:

curved probe

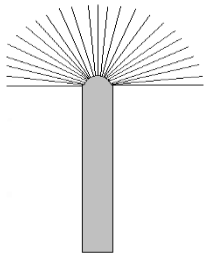


Phased array





Intra-cavity probe



Transducer use

- The sonographer asks the patient to take a deep breath and hold it. This brings the top of the liver out from under the ribs.
- Then the transducer is either moved in a straight line in a longitudinal or transverse direction, or else rocked back and forth in one place.
- Procedure will produce a two-dimensional scan on the screen.
- The sonographer scans the rest of the liver and takes pictures of areas of interest

2- Central Processing Unit

- The CPU is the brain of the ultrasound machine.
- The CPU is basically a computer that contains the microprocessor, memory, amplifiers and power supplies for the microprocessor and transducer probe.
- The CPU sends electrical currents to the transducer probe to emit sound waves, and also receives the electrical pulses from the probes that were created from the returning echoes.
- The CPU does all of the calculations involved in processing the data.

Cont…

- Once the raw data are processed, the CPU forms the image on the monitor.
- The CPU does all of the calculations involved in processing the data.
- The CPU can also store the processed data and/or image on disk.

3- Transducer Pulse Control

- The transducer pulse controls allow the operator, called the **ultrasonographer.**
  - To set and change the frequency and duration of the ultrasound pulses, as well as the scan mode of the machine.
  - The commands from the operator are translated into changing electric currents that are applied to the piezoelectric crystals in the transducer probe.

5- Display

- The display is a computer monitor that shows the processed data from the CPU.
  - Displays can be black-and-white or color, depending upon the model of the ultrasound machine.

6- Keyboard / Cursor

- Ultrasound machines have a keyboard and a cursor, such as a trackball, built in.
  - These devices allow the operator to add notes to and take measurements from the data.

7- Disk Storage

- The processed data and/ or images can be stored on disk.
- The disks can be hard disks, floppy disks, compact discs (CDs) or digital video discs (DVDs).
- Typically, a patient's ultrasound scans are stored on a floppy disk and archived with the patient's medical records.

8- Printer

- Many ultrasound machines have thermal printers that can be used to capture a hard copy of the image from the display.

How is the procedure performed?

- For most ultrasound exams, the patient is positioned lying face-up on an examination table that can be tilted or moved.
- A clear water-based gel is applied to the area of the body being studied to help the transducer make secure contact with the body and eliminate air pockets between the transducer and the skin that can block the sound waves from passing into your body.
- The sonographer (ultrasound technologist) or radiologist then presses the transducer firmly against the skin in various locations, sweeping over the area of interest or angling the sound beam from a farther location to better see an area of concern.

- Doppler sonography is performed using the same transducer.
- When the examination is complete, the patient may be asked to dress and wait while the ultrasound images are reviewed.
- In some ultrasound studies, the transducer is attached to a probe and inserted into a natural opening in the body. These exams include:
  - **Transesophageal echocardiogram.** The transducer is inserted into the esophagus to obtain images of the heart.
  - **Transrectal ultrasound.** The transducer is inserted into a man's rectum to view the prostate.
  - **Transvaginal ultrasound.** The transducer is inserted into a woman's vagina to view the uterus and ovaries.
  - Most ultrasound examinations are completed within 30 minutes to an hour.

Benefits vs risks?

Benefits:

- Most ultrasound scanning is noninvasive (no needles or injections) and is usually painless.
- Ultrasound is widely available, easy-to-use and less expensive than other imaging methods.
- Ultrasound imaging does not use any ionizing radiation.
- Ultrasound scanning gives a clear picture of soft tissues that do not show up well on x-ray images.
- Ultrasound is the preferred imaging modality for the diagnosis and monitoring of pregnant women and their unborn babies.
- Ultrasound provides real-time imaging, making it a good tool for guiding minimally invasive procedures such as needle biopsies and needle aspiration.

Risks

- For standard diagnostic ultrasound there are no known harmful effects on humans.

Ultrasound uses

1. Ultrasound examinations can help to diagnose a variety of conditions and to assess organ damage following illness.

2. Ultrasound help the physicians to evaluate symptoms such as:

- Pain
- Swelling
- Infection
- Hematuria (blood in urine)

3. Ultrasound is a useful way of examining many of the body's internal organs, including:

- Heart and blood vessels, including the abdominal aorta and its major branches
- Liver
- Gallbladder
- Spleen
- Pancreas
- Kidneys
- Bladder
- Uterus, ovaries, and unborn child (fetus) in pregnant patients
- Eyes
- Thyroid and parathyroid glands
- Scrotum (testicles)
- brain in infants
- hips in infants

4. Ultrasound is also used to:

- Guide procedures such as **needle biopsies**, in which needles are used to extract sample cells from an abnormal area for laboratory testing.

- Image the breasts and to guide **biopsy** of breast cancer

- Diagnose a variety of heart conditions and to assess damage after a heart attack or diagnose for **valvular** heart disease.

5. Doppler ultrasound images can help the physician to see and evaluate:

- blockages to blood flow (such as clots).
- narrowing of vessels (which may be caused by **plaque**).
- tumors and congenital vascular malformation.

With knowledge about the speed and volume of blood flow gained from a Doppler ultrasound image, the physician can often determine whether a patient is a good candidate for a procedure like **angioplasty**.

Limitations of Ultrasound Imaging?

- Ultrasound waves are disrupted by air or gas; therefore ultrasound is not an ideal imaging technique for air-filled bowel or organs obscured by the bowel. In most cases, barium exams, CT scanning, and MRI are the methods of choice in this setting.

- Large patients are more difficult to image by ultrasound because greater amounts of tissue attenuates (weakens) the sound waves as they pass deeper into the body.

- Ultrasound has difficulty penetrating bone and, therefore, can only see the outer surface of bony structures and not what lies within (except in infants). For visualizing internal structure of bones or certain joints, other imaging modalities such as MRI are typically used.

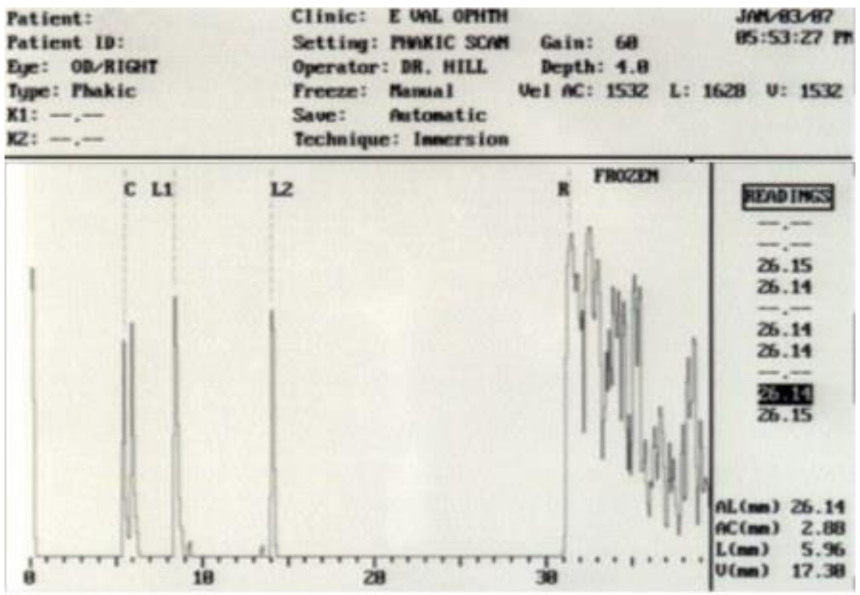
ULTRASOUND IMAGING MODES

- A-Mode
- B-Mode
- M-Mode

A-Scan

A-Scan (Amplitude scan)

- Gives no photo image Pulses of ultrasound sent into the body, reflected ultrasound is detected and appear as vertical spikes on a CRO screen.
- The horizontal positions of the 'spikes' indicate the time it took for the wave to be reflected.
- Commonly used to measure size of foetal head and ophthalmologic intraocular length measurements.



B-Scan

B-Scan (Brightness scan)

- An array of transducers are used and the ultrasound beam is spread out across the body.
- Returning waves are detected and appear as spots of varying brightness.
- These spots of brightness are used to build up a picture.

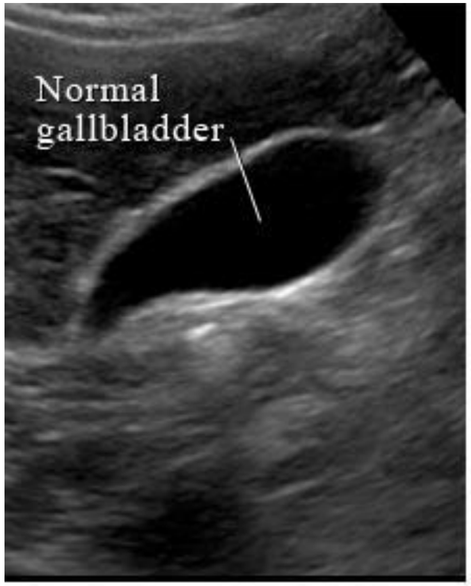


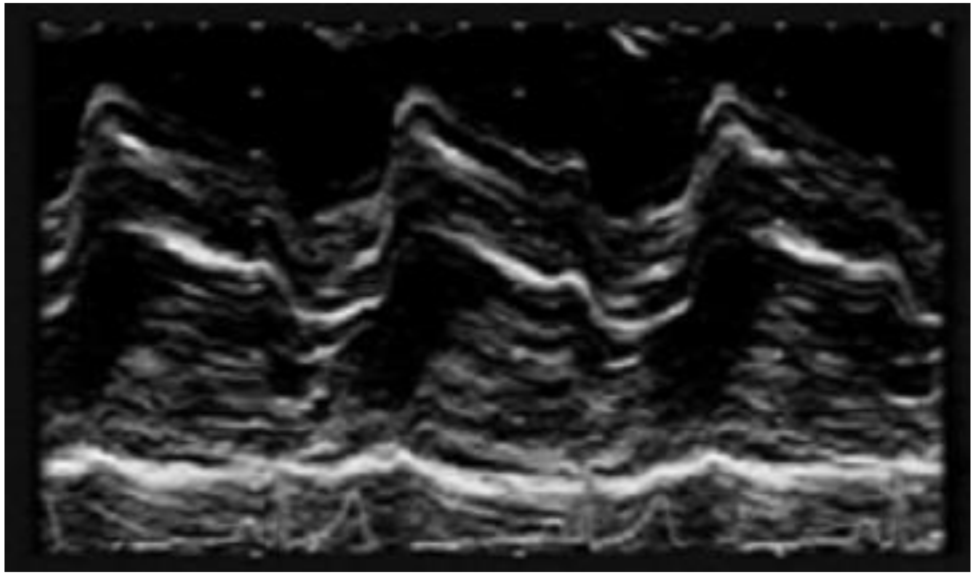
Figure 1

Figure 2

M-Mode

M-Mode (Motion Mode)

- One-dimension image used to investigate moving structures with respect to time
- Evaluates motion pattern of moving structures such as in the heart



M-Mode display of mitral valve leaflet of a beating heart