Department of Systems and Biomedical Engineering

Cairo University

SBE 405 Medical Instrumentation IV: Ultrasound Imaging

Ahmed M. Ehab Mahmoud, PhD

Department of Biomedical Engineering and Systems, Cairo University, Giza, Egypt.

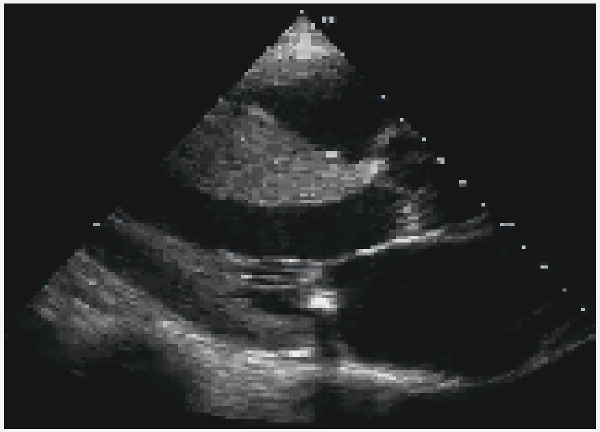
Office: Medical Equipment Calibration Laboratory, 2nd floor, Architecture building, Faculty of Engineering.
Email: a.ehab.Mahmoud@gmail.com
a.e.mahmoud@ieee.org

Why Ultrasound Imaging?

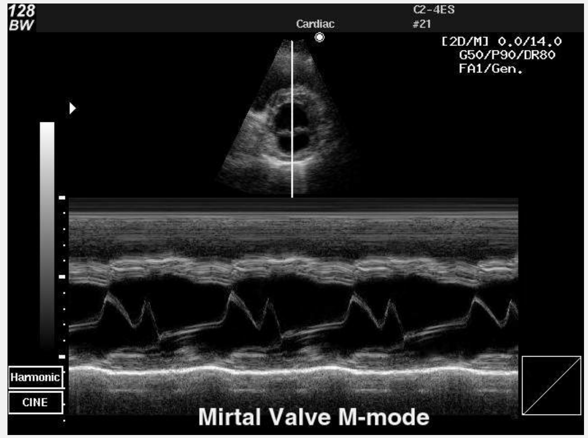
Course Motivation:

As "biomedical engineers", it is important to understand the physics, design, and types of ultrasound imaging modalities as common diagnostic tools in healthcare facilities.

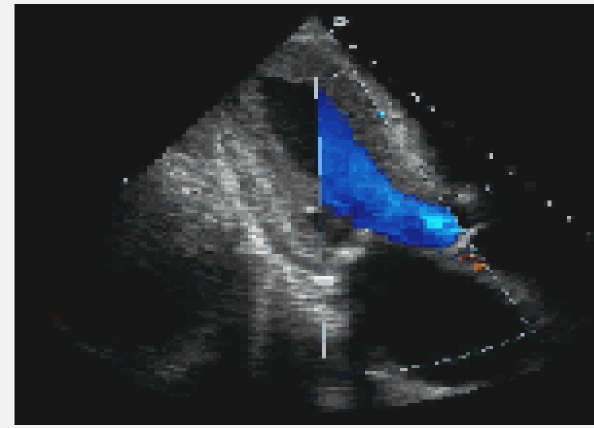
What Ultrasound Imaging Can Do?



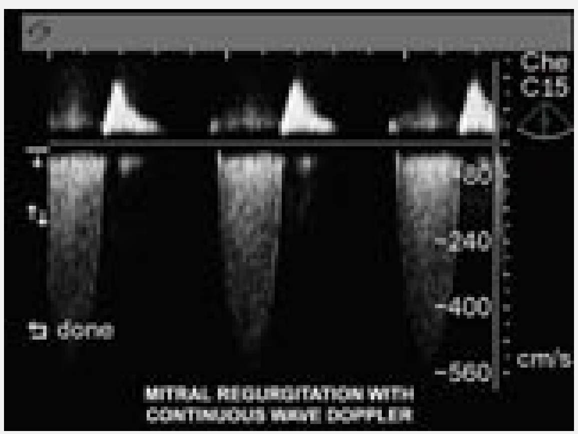
B-Mode (Real time)



M- Mode



Color Doppler



Doppler

Intravascular

3 D Ultrasound

Syllabus

Lecture: Wednesdays, 8:30-10:00 AM and/or 10:15-11:45 AM. Online sessions may be used instead.

Office Hours: Appointments by email

Teacher Assistant (TA): Eng. Ola Sarhan

Course Materials: Lecture notes, assignment, homework, and other course materials may be sent electronically via email group. Please check with TA

Course Content

- Physics of ultrasound
- Fundamentals of Acoustic Propagation
- Ultrasonic Transducers and Arrays
- Ultrasound Imaging Modes and Instrumentation
- Doppler Flow Measurements
- Biological Effects and Safety

Syllabus

Textbook Reference:

1. Diagnostic Ultrasound: Physics and Equipment, 2nd ed., by Peter R. Hoskins (Editor), Kevin Martin (Editor), Abigail Thrush (Editor) Cambridge University Press, 2010.

Other References

2. Diagnostic Ultrasound: Imaging and Blood Flow Measurements, 1st ed, K. Kirk Shung, CRC Press, 2010.
3. Other materials including internet-based.

Grading:

75 % final & 25% coursework that includes:

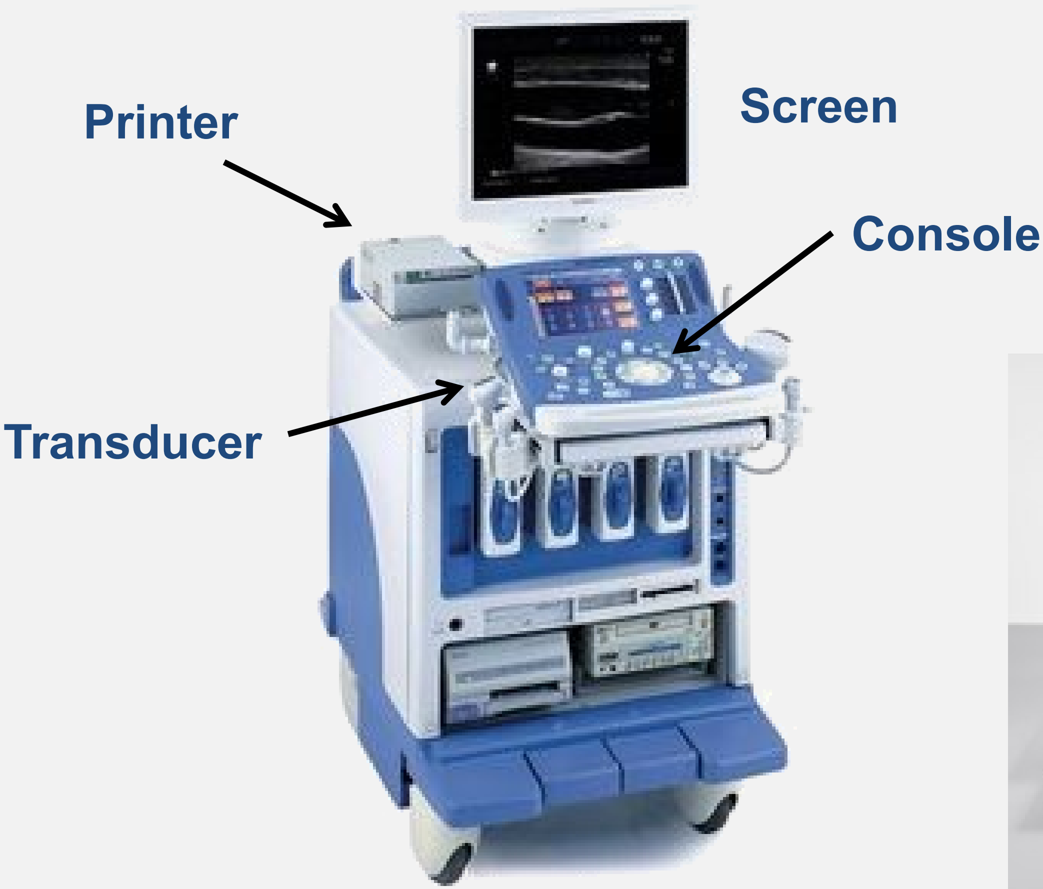
- Midterm
- Homework, quizzes and/or presentations

Policies

Cheating is prohibited and will not be tolerated.
This includes homework, exams, etc. Cheating penalty may result in a zero-point score for all people involved.

Ultrasound Machine

Conventional



Handheld

Portable

Role of Ultrasound in Medical Imaging

Ultrasound not only complements other modalities such as x-ray, but also has unique characteristics that are advantageous in comparison to other competing modalities as follows :

- Ultrasound is a form of nonionizing radiation and considered safe to the best of present knowledge.
- It is less expensive than imaging modalities of similar capabilities.
- It has a resolution in the millimeter range, which may be improved if the frequency is increased.
- It is mobile and portable and thus can be easily transported to the bedside of a patient

Kirk Shung, Diagnostic Ultrasound: Imaging and Blood Flow Measurement.

Drawbacks of Ultrasound Imaging

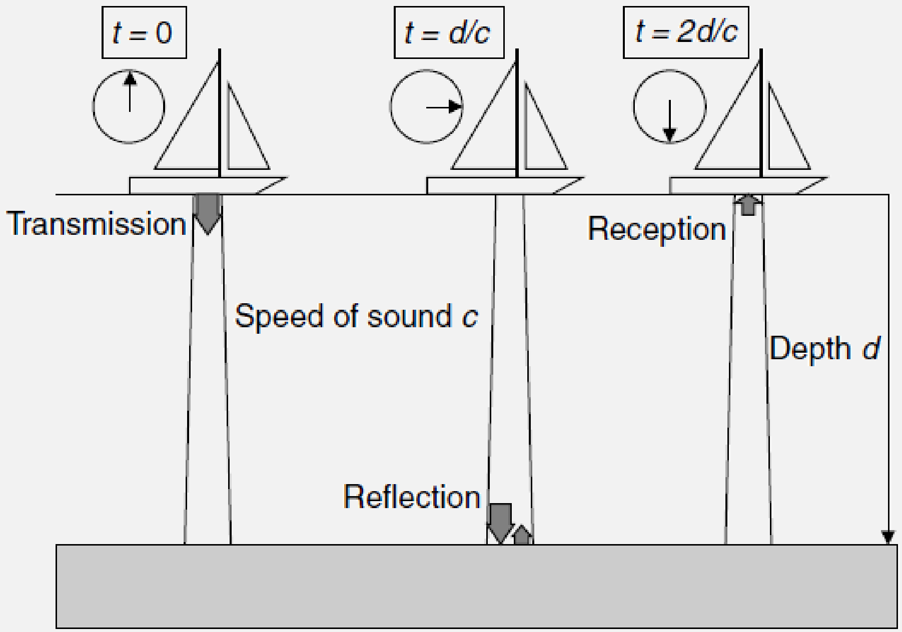
Ultrasound also has some drawbacks including:

- Organs containing gases and bony structures cannot be adequately imaged without introducing specialized procedures.
- Only a limited window is available for ultrasonic examination of certain organs, such as heart and neonatal brain.
- It depends on operator skill.
- It is sometimes impossible to obtain good images from certain types of patients, including obese patients.

Kirk Shung, Diagnostic Ultrasound: Imaging and Blood Flow Measurement.

Basic Idea

- Send waves into body which are reflected at the interfaces between tissue.
- Return time of the waves tells us of the depth of the reflecting surface.

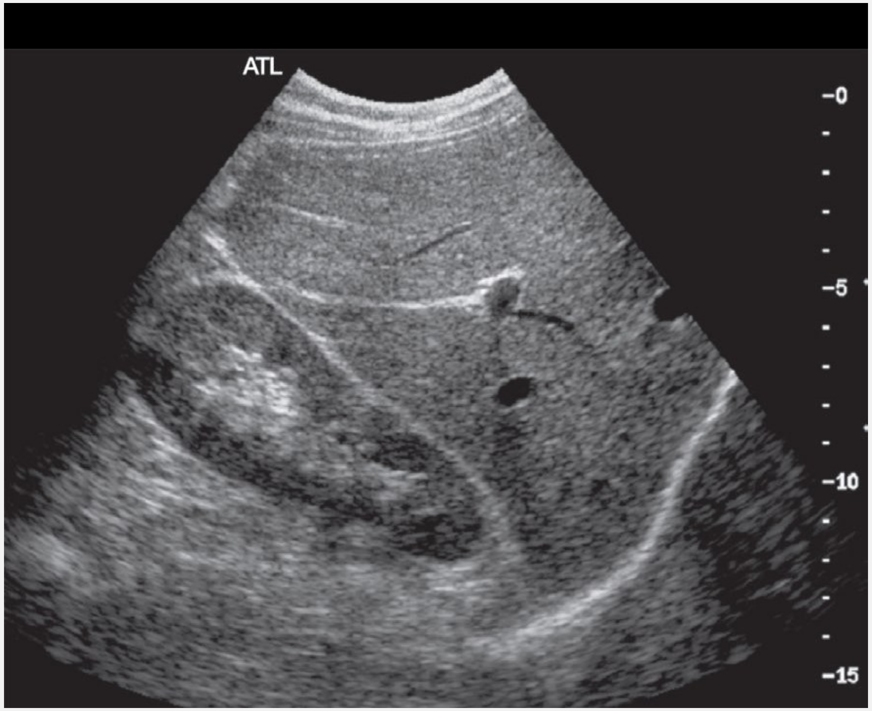


History

- The potential of ultrasound as an imaging modality was realized as early as the late 1940s when utilizing sonar and radar technology developed during World War II. Several groups of investigators around the world started exploring diagnostic capabilities of ultrasound
- WW II brought massive military research - SONAR (Sound Navigation And Ranging)
- Mid-century used for non-destructive testing of materials
- 1950’s 2D gray scale images
- 1965 or so real-time imaging

Principles of Ultrasound

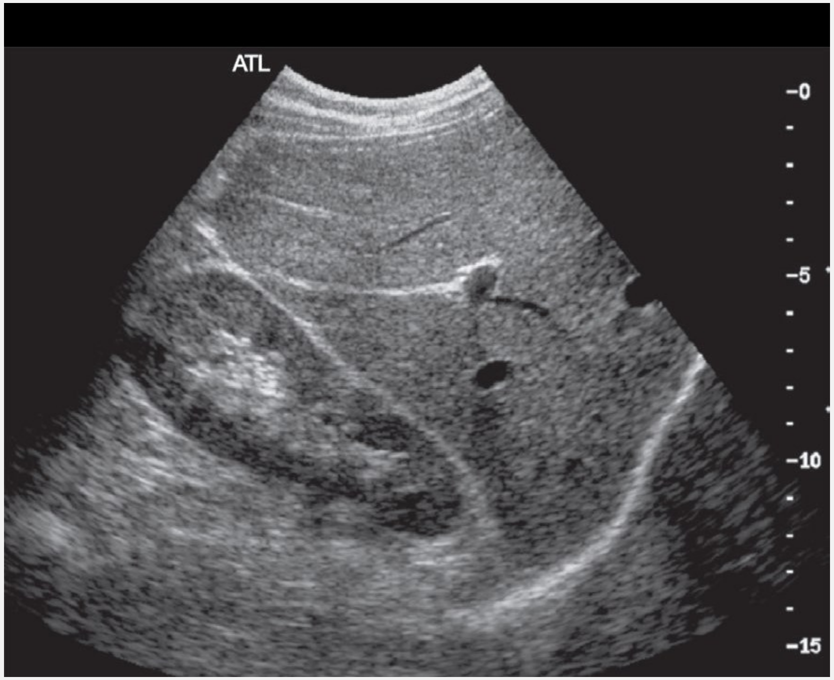
- A brightness mode (B-mode) image is a cross-sectional image representing tissues and organ boundaries within the body.
- It is constructed from echoes and scattering from small irregularities within tissues.



An example of a B-mode image showing reflections from organ and blood vessel boundaries and scattering from tissues.

Principles of Ultrasound

- Each echo is displayed at a point in the image, which corresponds to the relative position of its origin within the body cross section, resulting in a scaled map of echo-producing features.
- The brightness of the image at each point is related to the strength or amplitude of the echo, giving rise to the term B-mode (brightness mode).



An example of a B-mode image showing Reflections from organ and blood vessel boundaries and scattering from tissues.

Physics of Ultrasound

- Ultrasound are mechanical longitudinal waves that require a physical medium to propagate through.
- "Ultrasound" refers to frequencies greater than 20 kHz, the limit for human hearing.
- The frequency range used for medical imaging is about 100 times higher than human audible. Typically, 2-20 MHz.

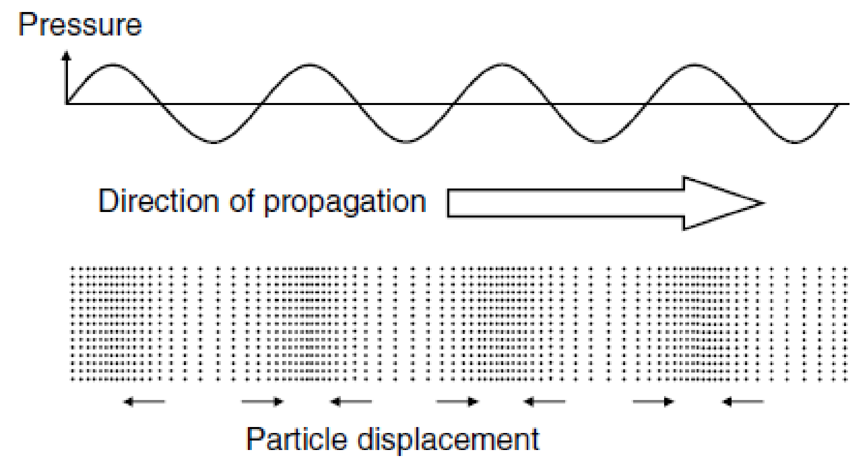
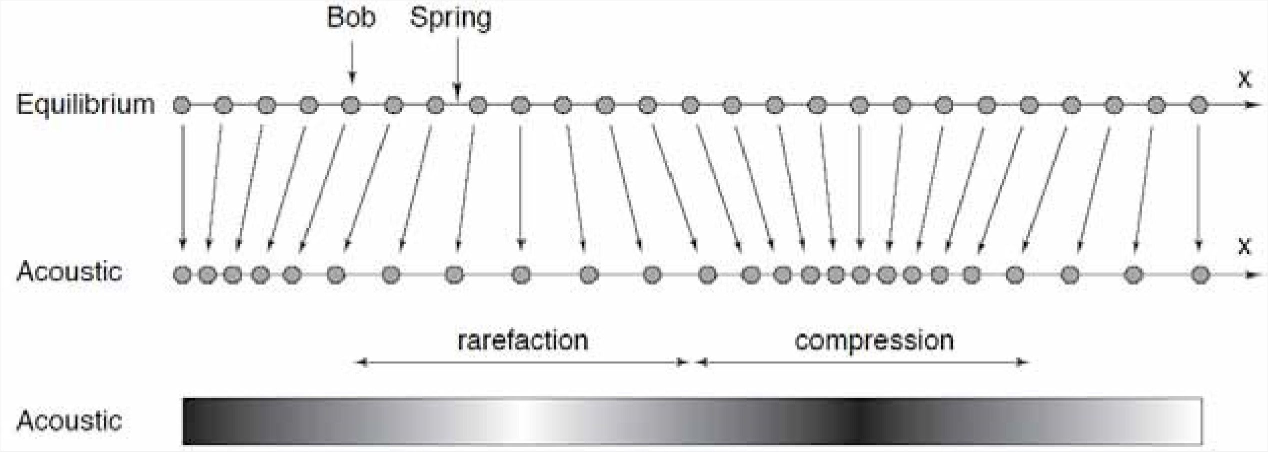


Fig. 2.2 In a longitudinal wave, particle motion is aligned with the direction of travel, resulting in bands of high and low pressure.

- Particles of the medium oscillate backwards and forwards along the direction of propagation.

Physics of Ultrasound

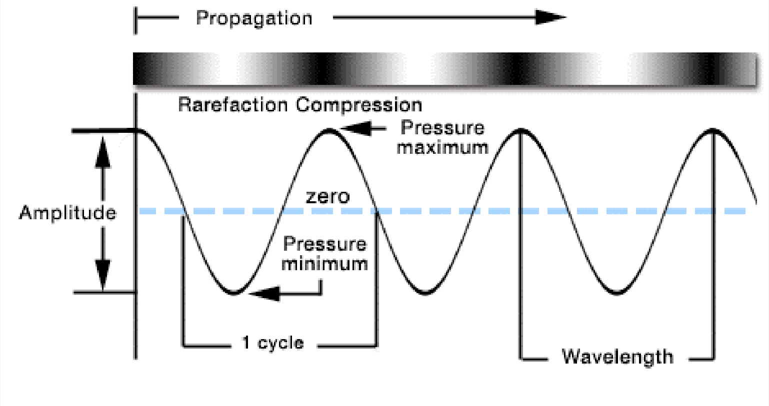
- When particles move towards each other, a region of compression results, but where particles moves apart, a region of rarefaction results.
- There is no net movement of the medium. Only the disturbance and its associated energy are transported



Physics of Ultrasound

- The **frequency (*f*)** of the wave is the number of oscillations or wave crests passing a stationary observer per second and is determined by the source of the sound wave. (1 Hz = 1 cycle per second)
- The **wavelength (*λ*)** is the distance between consecutive wave crests or other similar points on the wave.
- The **speed/velocity (*c*)** is determined by the medium in which it is travelling. Examples are the speed of sound in air (330 m s −1) and water (1480 m s −1).

$$c=\lambda f$$



Physics of Ultrasound

- Sound speed is determined by the medium it is travelling in.
- The material properties which determine the speed of sound are density (ρ) and stiffness (K).

$$\text{Speed of sound } c = \sqrt{k/\rho}$$

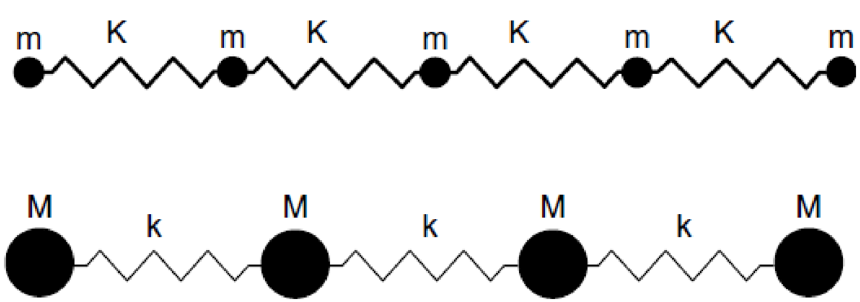


Fig. 2.6 The speed of sound in a medium is determined by its density and stiffness, which can be modelled by a series of masses and springs.

Table 2.1 Speed of sound in human tissues and liquids (from Duck 1990).

Material	c (m s^{-1})
Liver	1578
Kidney	1560
Amniotic fluid	1534
Fat	1430
Average tissue	1540
Water	1480
Bone	3190–3406
Air	333

Physics of Ultrasound

- As a sound wave passes through a medium, the particles are displaced backwards and forwards from their rest positions in a repeating cycle like a paddle.
- The pattern of particle displacement with time can be described by a sine wave.
- **The phase** (θ) of the pedal is its position within such a cycle of rotation and is measured in degrees.

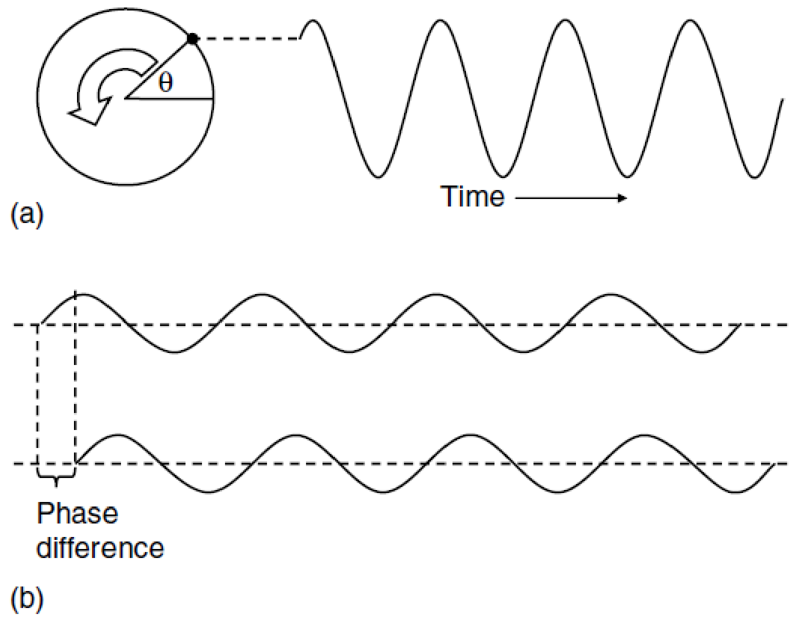
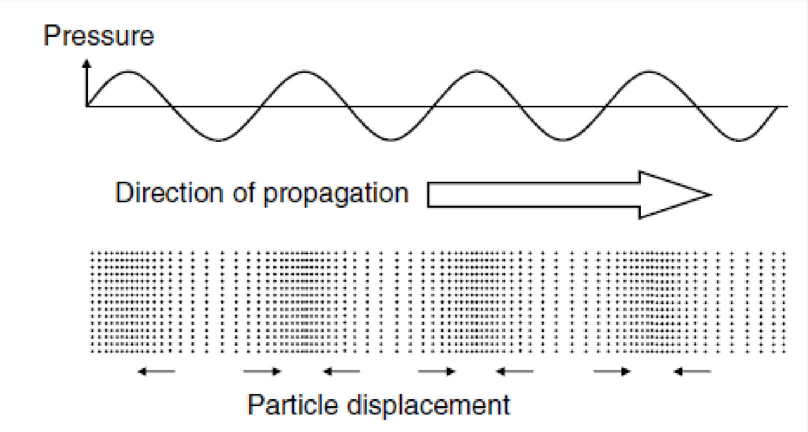


Fig. 2.4 (a) Phase describes the position within a cycle of oscillation and is measured in degrees. (b) Two waves of the same frequency and amplitude can be compared in terms of their phase difference.

Acoustic Pressure

- The difference between this actual pressure and the normal rest pressure in the medium is called the excess pressure, *p* , which is measured in pascals (Pa).
- For longitudinal waves, the acoustic pressure can be related to the underlying particle velocity (*u*) as follows: $$p = uZ$$



where *Z* is called the characteristic impedance
This is a like V=IR,

Note that $u \neq c$