Mechanical Waves

Sanjin Zhao

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Learning Outcome

I highly recommend you to finish this checklist to determine whether you've achieved the learning objectives.

- ☐ describe a progressive wave
- ☐ describe the motion of transverse and longitudinal waves
- ☐ describe waves in terms of their *wavelength*, *amplitude*, *frequency*, *speed*, *phase difference* and *intensity*
- ☐ use the time-base and y-gain of a *cathode-ray oscilloscope (CRO)* to determine frequency and amplitude
- ☐ use the wave equation $v = f \cdot \lambda$ and $f = {}^{1}/_{T}$
- ☐ use the equations of intensity and its relationship with amplitude.

Leadin

Vibration in matters can **transfer energy** through the media. Let's give your several examples: *ripple*, *sound* and *seismic waves*[1]

But we have more to explore in a quantitative way. In this chapter we need to define waves, and describe waves.

[1] def:

Figure 1: The ripples is a vibration of water molecules

Progressive Waves

Waves can be classified, based on whether the propogation needs medium or not, into *Mechanical Waves* and *Eletromagnetic Waves*. And if a wave carries energy from one place to another, such wave is called "**progressive**"

Vibration and Pulse

In the Phet simulation, by vibrating the water by droplet or vibrating the drum, we can create a pulse. As time pass by, the single pulse can spread to further place.

Another case is on spring, play the pulse on string simulation. and you will find it is no different from the water surface example.

As we vibrate some matter, we can see a *pulse*[2] forms on the matter and the pulse can spread.

[2] def:

As long as we keep the vibration on the matterial, the wave patterns will form in that matterial. And such phenomonon is called waves.

Summary

wave is ____________________ travelling through space, characterised by a vibrating medium.

Transverse Wave

A wave has a direction of *propagation*, but another direction exist at which the particles in the medium is vibrating. When the two direction are *perpendicular*, the wave is defined as *transverse wave*.

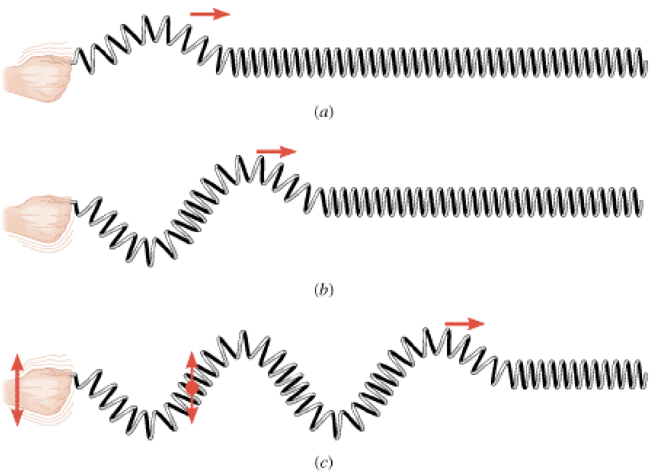


Figure 2: a transverse wave on a slinky spring

Task

On Fig.2, label the direction of propagation and the direction of vibration, accroding to this characteristic, define what is Transverse wave.

Longitudinal Wave

There is another way to vibarate the slinky spring, as illustrated in Fig.3.

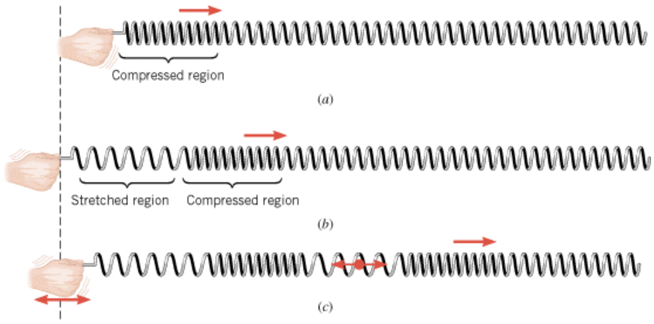


Figure 3: a longitudinal wave on a slinky spring

This time, the vibration direction is **parallel to** the direction of spread. Hence, such wave is called *Longitudinal Wave*.

A most common longitudinal wave is sound, think what is the medium that sound can spread by? The answer is the air molecules[3].

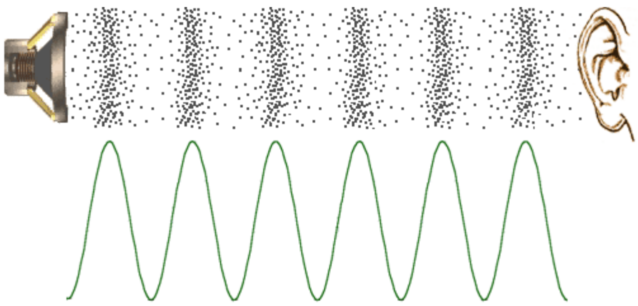


Figure 4: Small dots represent air molecules

[3] In chemistry, there is no air molecules, since it is a mixture. The small dots representsO_2,N_2,Ar,CO_2,H_2O, which are the consituents of the air.

Surface Wave

The seismic waves are spreading in all directions, thus we call it a surface wave. It is a little complicated since both transverse and longitudinal waves exist. But it is not the focus in this lesson.

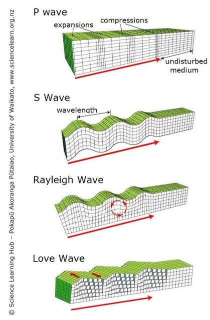


Figure 5: P-wave and S-wave in an earthquake

Wave as form of energy transfer

No matter in which type of waves, the matter itself only vibrates in limited region, it cannot spread with the wave. So pulse or wave **can transfer energy** but **can not transfer matter**.

CRO

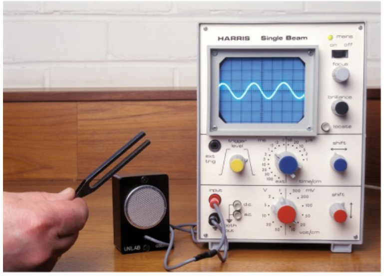


Figure 6: A CRO measuring the variation of air with time.

Cathode-Ray Oscilloscope(CRO) is an important instrument in studying the waves, AC currents.

The main function is to show the variation of voltage, or vibration of a **fixed point** on the way of wave propagation.

d-t graph of a point

With CRO, a *d*-*t* graph of a point can be determined, as shown in Fig.7.

Figure 7: A sine pattern in an oscilloscope

The buttons on oscilloscope can adjust the **time-base** and **y-gain** of the graph to have a more comfortable diagram when studying the wave patterns. This is the *d*-*t* graph of a fixed point on wave.

You can play with the virtual oscilloscope to grasp the skill to operate with CRO.

d-x graph of the wave

In Fig.2, A similar sinusoidal pattern resembles 7. However, the mechansim of forming such pattern is completely different. It shows the displacement

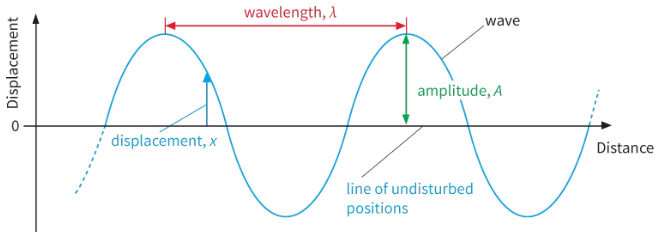


Figure 8: a *d*-*x* graph of a wave

of all position in a wave within the same time momement. CRO couldn't achieve such.

> **Task**
>
> Compare *d*-*t* graph of a point v.s. *d*-*x* graph of a wave.

Describing Waves

With the help of CRO or other devices, now the wave patterns can be studies thoroughly from a quantitative perspective. All the physical quantities can be obtained either from the d-x graph or the d-t graph.

Equilibrium Position

When there is no vibration source, all the point in the medium are said to be in equilibrium position.

> **Task**
>
> Label the equilibrium positions in Fig.8.

Peak and Trough

When a progressive wave forms in a medium, peak and trough are speical controlling points in the wave.

> **Task**
>
> Label the crests and troughs in Fig.8.

Compression and Rarefraction

In Fig.3 and Fig.4, since the direction of vibration is parallel to the direction of propagation, the pattern is different from the transverse wave, But the Compression and Rarefraction are similar to the peak and trough in transverse waves.

> **Task**
>
> Label the crests and troughs in Fig.4.

With the help of CRO, the pattern can be transformed into a sine wave by measuring the **displacement** or **air pressure**[4].

[4] this needs further explaination

Amplitude

The amplitude is the ____.

> **Task**
>
> Label the amplitude in Fig.2 and Fig.4(b).

Wavelength, λ

wavelength, λ, is the distance between two adjacent points on a wave oscillating **in step with** each other.

Task

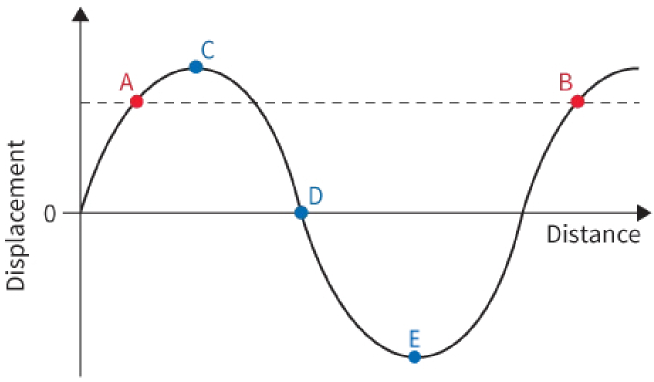
please explain how to define the phrase “in step with” by your own word.

And wavelength can only be obtained through (*d-t* graph/*d-x* graph).

Phase Differnce

As sinuosoidal function is a periodic function, which means after 2π or 360°, the function will repeat itself. This properties can be shown in *d-x* graph, in which certain points will vibrate *in phase*, while some point will vibrate *out of phase*. And most position are having phase difference[5].

[5] it is related with the sine function, which may require your deep understanding in trigonometric function



Points A and B are vibrating; they have a phase difference of 360° or 0°. They are ‘in phase’.

Points C and D have a phase difference of 90°.

So when two points in the material vibrate **in phase**, that means they are vibrating with same dispalcement at any time, the phase differnce between them is a **multiple of** 360°.

When two points in the material vibrate **out of phase**, that means they are vibrating with completely opposite dispalcement at any time, the phase differnce between them is a **odd multiple of** 180°.

Period

Summary

Define Period.

Period is the time taken to ______________________________

Keep in mind that, period, T, can only be found on the *d-t* graph.[6]

[6] some question in AS Level paper1 will ask you to determine the period from a CRO diagram.

Frequency

Frequncy, f, is the number of oscillations per unit time of a point in a wave. The unit for frequency is Hz, and the SI base unit for Hz is ______________. According to the relationship between **Period** and **Frequency**, the larger the period is, the smaller frequency is.

$$f = \frac{1}{T} \qquad T = \frac{1}{f}$$

Wave Speed

How fast that a wave can spread in the unit time is called the wave speed. For example, the sound wave can have a typical speed of $330\,\mathrm{m\,s^{-1}}$ at normal temperature.

Example

Let's determine the wave speed from wavelength λ and frequency, f or period T.

$$\text{speed} = \frac{\text{wavelength}}{}$$

Hence:

$$\begin{aligned} v &= \frac{\lambda}{T} \\ &= \frac{1}{T} \cdot \lambda \\ &= f \cdot \lambda \end{aligned}$$

The equation holds true for any wave.

Wave Intensity

intensity def

As told before, the wave is a way of transferring energy, not matters. Thus the rate of energy transmitted (power) __________ at right angles to the wave velocity is defined as *intensity*.

$$\text{intensity} = \underline{}$$

intensity and amplitude

with the case of sound, if you beat a drum or pluck the strings of a guitar more violently, you would hear a much louder sound, which means larger energy is transferred hence large intensity.

Task

which property of wave changes when you beat a drum more violently?

Hence, the relationship is deduced, the larger the amplitude of a wave, the larger of the intensity. Moreover, a square rule exist, which is:

$$\text{intensity} \propto \text{amplitude}^2 \qquad I \propto A^2$$