Phys 132 2022

Lecture 29

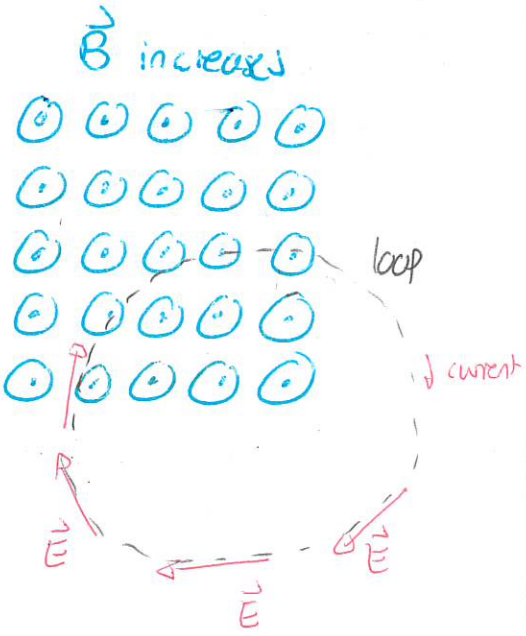
Tues:

Weds: Ex 179, 180, 181, 182, 183, 184, 185

Changing electric and magnetic fields

We have seen that a changing magnetic field will induce an EMF around any loop. The EMF can accelerate charges and we could therefore say

> A changing magnetic field induces an electric field around any loop



Such a field will exist regardless of the presence or absence of any conductor. The proper formulation of Faraday's Law describes precisely how such an electric field is related to the changing magnetic field.

Continuing this we can ask whether a changing electric field produces a magnetic field. Maxwell reasoned about this to conclude that

> An electric field that changes with time produces a magnetic field

Maxwell eventually condensed all of the existing electromagnetic theory into a set of equations describing how any sources produce fields.

Sources → Fields

Static charges
Time varying magnetic fields → Produce electric fields

Moving charges
Time varying electric fields → Produce magnetic fields

We see that there is a circular situation.

accelerating charges → Produce time varying magnetic fields → Produce time-varying electric fields

The proper formalism of electromagnetic theory using Maxwell's equations eventually addresses such situations.

Electromagnetic waves

Eventually Maxwell's equations can be manipulated to predict that even in a complete vacuum (no charges or currents) there can be electric and magnetic fields and that these fields can arrange themselves into wave-like patterns. These are called electromagnetic waves

Electromagnetic wave ⇝ wave of $\vec{E}$, $\vec{B}$ fields

Demo: Slide 1

Demo: Slide 2

Demo: PSU-S Electromagnetic Waves

Description of Waves

Describing electromagnetic waves requires much of the language used to describe waves in general. We can illustrate this with waves on a stretched string.

Demo: PhET W.O.a.S.

Settings: No end
Damping = none
Freq = 1.25 Hz
Tension = high.

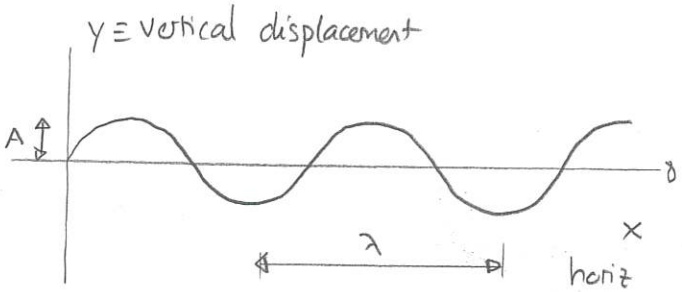
* Observe travelling wave (slow motion)
* Take snapshot

We have to analyze two features of such waves:

1) their spatial aspects - use a snapshot
2) their temporal aspects - watch as time passes

Consider a snapshot at one instant

Then the following are important:



Quantity	Symbol	Meaning
Amplitude	A (varies)	Maximum displacement from equilibrium
Wavelength	λ	Spatial repetition distance = distance between two successive points at the same location on the pattern
	Units: m	

Quiz 1 90%

A mathematically more convenient way to quantify the spatial repetition of a wave is via

wavenumber ≈ spatial repetition rate.

This is defined via

$$\text{wavenumber} = k = \frac{2\pi}{\lambda}$$

Units m^{-1}

Quiz 2

Mathematical representation of a wave at one instant.

Consider waves of the illustrated type. At any instant the displacement has a sinusoidal profile. We expect to describe this via a function

$$y = \text{const} \times \sin(\text{const}\, x)$$

Note that the maximum value sin can take is +1. The multiplying constant determines the amplitude of the wave. So we expect

$$y = A \sin(\text{const} \times x)$$

We consider the constant that multiplies x inside the argument of sin

Demo: Slide 3

We see that the term multiplying x describes the rate of change. The larger this term the higher the frequency and the smaller the wavelength

We have, exactly

$$y = A\sin(kx)$$

Using this we can show that any two horizontal locations separated by λ provide exactly the same displacement

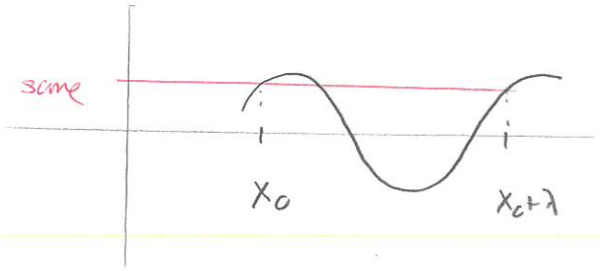
At x_0 $\quad y = A\sin(kx_0)$

At $x_0+\lambda$ $\quad y = A\sin(k(x_0+\lambda))$

$= A\sin(kx_0 + k\lambda)$

$\vdots$

$= A\sin(kx_0)$



This form is still not sufficiently general since at $x=0$ $\sin(kx)=0$. So it only describes waves where $y=0$ when $x=0$. A more general description involves an additional term in the argument

Demo: Slide 4

Thus we see that:

> At any one instant the profile of a sinusoidal wave is described by
>
> $$y = A\sin(kx+\phi)$$
>
> where ϕ is a constant called the phase of the wave.

Quiz 3 60% - 90%