

Part II: Quantum physics

Light travels at const speed c in vacuum (Roemer: 1676)

What is the nature of light?

Newton (1666) corpuscles [explains straight line motion]

vs.
Huygens (1690) waves [explains const speed]

Young (1801) 2-slit experiment demonstrates interference

Maxwell (1864) electromagnetic waves travel at c

$$\vec{E} = \vec{E}_0 \sin(\vec{k} \cdot \vec{x} - \omega t) \quad \text{with } \omega = c|\vec{k}|$$

ω = angular frequency (rad/sec)

$$f = \frac{\omega}{2\pi} = \text{frequency} \left(\frac{\text{cycles}}{\text{sec}} = \text{Hz} \right)$$

Planck (1900) explains blackbody spectrum

Einstein (1905) explains photoelectric effect

by asserting that energy of light waves is quantized.

Light consists of particles (photons) of energy

$$E = hf = \frac{h\omega}{2\pi} = \hbar\omega$$

where h = Planck's const
 $\hbar = \frac{h}{2\pi}$

wave-particle duality

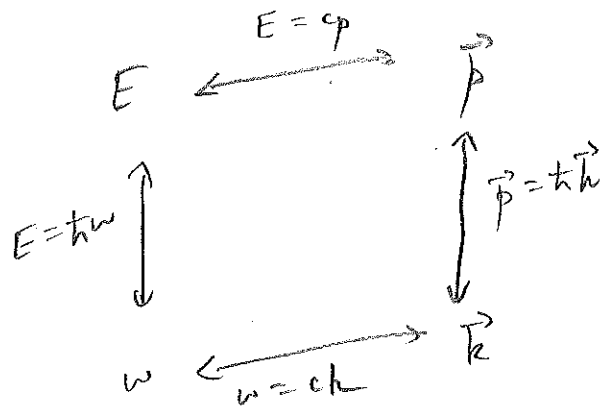
[not getting rid of wave picture]

Compton scattering (1923) demonstrated that

photons have momentum $p = \frac{E}{c}$

i.e. $E = cp$. Since $E^2 = (cp)^2 + (mc^2)^2$, this $\Rightarrow$ photons are massless

$$p = \frac{E}{c} = \frac{\hbar\omega}{c} = \hbar|\vec{k}| \Rightarrow \vec{p} = \hbar\vec{k}$$



$$\left. \begin{array}{l} E = \hbar\omega \\ \vec{p} = \hbar\vec{k} \end{array} \right\} \Rightarrow p^\mu = \hbar k^\mu$$

$$\vec{E} = \vec{E}_0 \sin(\vec{k} \cdot \vec{x} - \omega t)$$

$$= \vec{E}_0 \sin\left(-\frac{\vec{p} \cdot \vec{x}}{\hbar} - \frac{Et}{\hbar}\right) \quad \text{describes a travelling wave}$$

The wave equation is a linear equation

$$\frac{\partial^2 A}{\partial t^2} - c^2 \frac{\partial^2 A}{\partial x^2} = 0$$

[each term contains only one factor of A]

$\Rightarrow$ linear combinations of solutions are also solutions

If $A_1 + A_2$ are solutions, so is $\alpha A_1 + \beta A_2$
for const α, β

Travelling wave solutions $\sin(kx - \omega t)$
can be written as linear combinations of
standing wave solutions $\sin(kx) \cos(\omega t)$,
 $\sin(kx) \sin(\omega t)$

and vice versa.

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Exercise

use trig identities to express a standing wave

$$s_i = (kx) \cos(\omega t)$$

as a superposition (linear comb.) of travelling wave

(Answer. $\sin(kx) \cos(\omega t) = \frac{1}{2} (\sin(kx + \omega t) + \sin(kx - \omega t))$)

After answer is presented in class; go over this:

Comment: because the wave eqn is linear (in A), any linear comb. of solutions is also a solution

Math tricks:

You should memorize these!

$$\begin{aligned} \cos(A+B) &= \cos A \cos B - \sin A \sin B \\ \sin(A+B) &= \sin A \cos B + \sin B \cos A \end{aligned}$$

Then use $\cos(-B) = \cos B$ (even) and $\sin(-B) = -\sin B$ (odd)

to recall (don't memorize)

$$\begin{aligned} \cos(A-B) &= \cos A \cos B + \sin A \sin B \\ \sin(A-B) &= \sin A \cos B - \sin B \cos A \end{aligned}$$

Also know special cases: $A=B$

$$\begin{aligned} \Rightarrow \cos 2A &= \cos^2 A - \sin^2 A \\ \sin 2A &= 2 \sin A \cos A \end{aligned}$$

In the second set of formulae, $A=B$ gives

$$\begin{aligned} \cos 0 &= 1 = \cos^2 A + \sin^2 A \quad \checkmark \\ \sin 0 &= 0 = 0 \end{aligned}$$

Note to instructor:
[These will appear soon when introducing complex plane!]

already recalled in earlier years
or maybe