Wave-Particle Duality

Einstein:
momentum of a photon

$$p = \frac{h}{\lambda}$$

Wave-Particle Duality

from: $\lambda \nu = c$ **and** $E = h\nu$

↓

$$E = \frac{hc}{\lambda}$$

Wave-Particle Duality

use Einstein's relativity result $E = mc^2$

$$\lambda = \frac{h}{mc}$$

Note that m **refers to the relativistic mass, not the rest mass**

Wave-Particle Duality

1924 de Broglie:
matter also can exhibit this
wave-particle duality

$$\lambda = \frac{h}{mV}$$

Wave-Particle Duality

1927, Davisson and Germer:
observed diffraction patterns by bombarding metals with electrons, confirming de Broglie's proposition

Wave-Particle Duality

de Broglie's equation offers a justification for Bohr's assumption

If we think of an electron as a wave, then for the electron orbit to be stable the wave must complete an integral number of wavelengths during its orbit. Otherwise, it would interfere destructively with itself.

Wave-Particle Duality

This condition may be written as

$$2\pi r = n\lambda$$

$$mvr = n\hbar$$

which is identical to Bohr's equation

Uncertainty principle

Heisenberg: the wave-particle duality leads to the famous uncertainty principle

$$\Delta x \, \Delta p \approx h$$

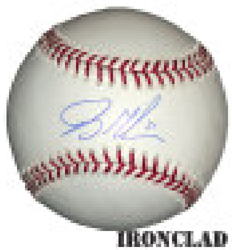
Uncertainty principle

One result of the uncertainty principle:
if the orbital radius of an electron in an atom (*r*) is known exactly,
then the angular momentum must be completely unknown.

Uncertainty principle

Example:

Calculate the uncertainty in the position of a baseball thrown at 40 m/s if we measure its velocity to a millionth of 1%.



$$= 0.14kg$$

$$P = mv = 0.14kg \times 40ms^{-1}$$

$$= 5.6kgms^{-1}$$

Uncertainty principle

a millionth of 1%

$$= 5.6 \times 10^{-8} kgms^{-1}$$

Uncertainty principle

$$\Delta x = \frac{h}{\Delta p} = \frac{6.626\times10^{-34}\,Js}{5.6\times10^{-8}\,kgms^{-1}}$$

$$=1.2\times10^{-26}\,m$$

Uncertainty principle

Example:

What is the uncertainty in momentum if we wish to locate an electron within an atom, say, so that Δx is approximately is 50pm?

Uncertainty principle

$$\Delta p = \frac{h}{\Delta x} = \frac{6.626\times10^{-34}\,Js}{50\times10^{-12}\,m}$$

$$= 1.3\times10^{-23}\,kgms^{-1}$$

Uncertainty principle

P = mV

ΔP corresponds to

$$\Delta v = \frac{\Delta P}{m} = \frac{1.3 \times 10^{-23} kgms^{-1}}{9.11 \times 10^{-31} kg}$$

$$= 1.4 \times 10^{7} ms^{-1}$$