PARTICLE PROPERTIES OF WAVES

1. Electromagnetic Waves.
2. Blackbody Radiation.
3. Photoelectric Effect.
4. What is Light?
5. X-Rays.
6. X-ray Diffraction.
7. Compton Effect.
8. Pair Production.
9. Photons and Gravity.

WHAT IS LIGHT?

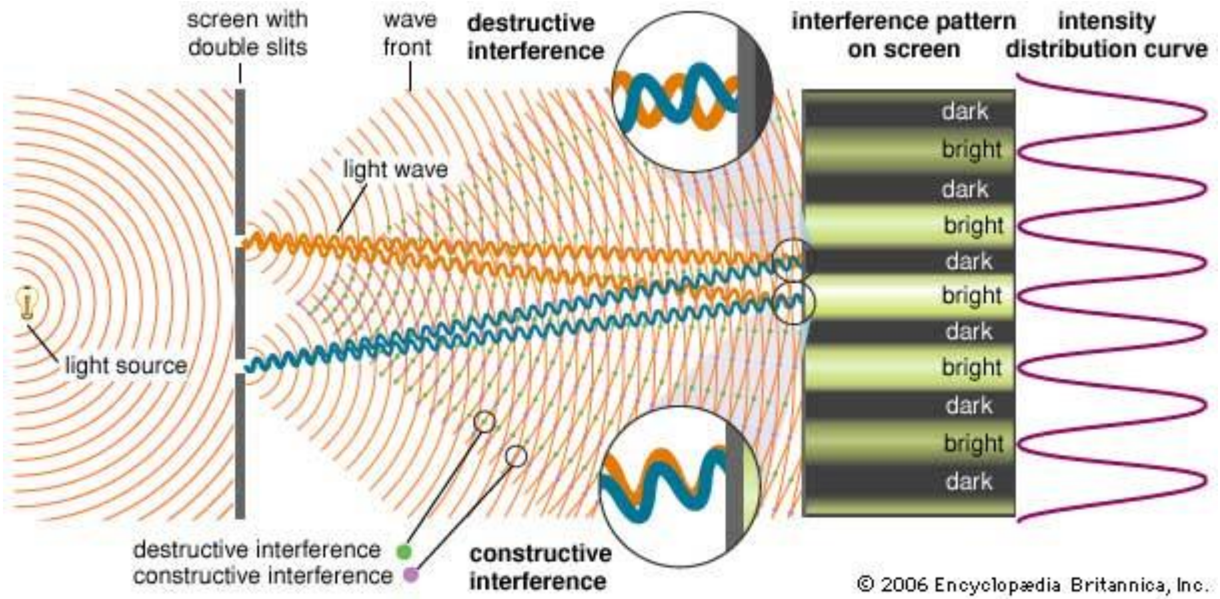
Phenomena	Can be explained by wave theory	Can be explained by particle theory
Reflection	✓	✓
Refraction	✓	✓
Interference	✓	✗
Diffraction	✓	✗
Polarization	✓	✗
Blackbody radiation	✗	✓
Photoelectric effect	✗	✓

Which theory are we to believe? ← all have experimental proof!!

WHAT IS LIGHT?

Wave model:

The intensity $\propto \overline{E}^2$



Both should give the same value for the intensity!!

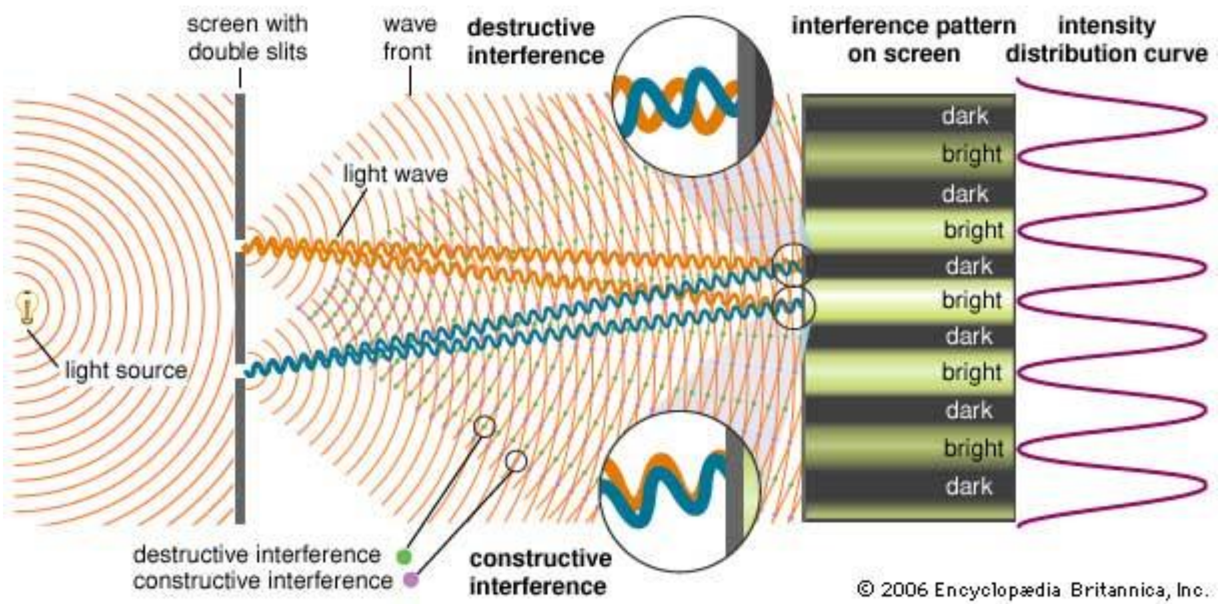
Particle model:

The intensity $\propto Nh\nu$

Probability of finding a photon at a certain place & time depends on $\overline{E}^2$

WHAT IS LIGHT?

How can we link these concepts together?



Wave model:

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Particle model:

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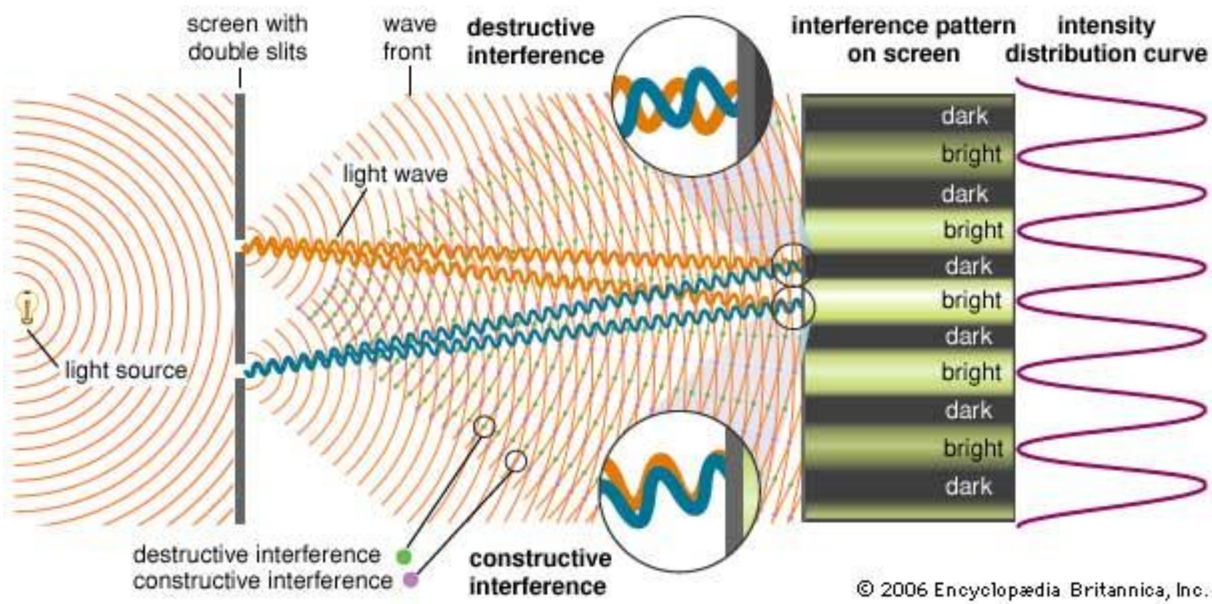
WHAT IS LIGHT?

How can we link these concepts together?

Wave model:

Photons travel as waves



The wave and quantum theory complement each other.

Particle model:

Photons absorb and give off energy as a particle

LIGHT HAS A DUAL CHARACTER!!

WHAT IS LIGHT?

Remember....

Light has a dual nature..
It is both a wave and a particle...

X-Rays

From the photoelectric effect:
It proved that photons of light can transfer energy to electrons.

Is the inverse process also possible??

The inverse photoelectric effect was discovered long before Planck and Einstein!

Roentgen in 1895 found highly penetrating radiation of unknown nature when fast electrons impinge on matter.

X-Rays

<u>These X-ray radiation are found to be:</u>

1. Travel in straight lines.
2. Unaffected by electric and magnetic fields.
3. Pass through opaque materials.
4. Cause phosphorescent substances to glow.
5. Expose photographic plates.
6. The faster the electrons the more penetrating the x-rays.
7. The greater the number of electrons, the greater the intensity of the x-ray beam.

X-Rays

It became clear soon after the discovery of X-rays that they are EM waves.

According to EM theory..

- Accelerated electric charge will radiate EM waves.
- Rapidly moving electrons suddenly brought to rest is certainly accelerated.

Radiation produced under these circumstances is know as Bremsstrahlung ("breaking radiation").

The greater the energy of an electron and the greater the atomic number of the nuclei it encounters, the more energetic the bremsstrahlung.

X-Rays

How can we measure the wavelengths of X-rays?

• From physical optics, the spacing between adjacent lines on a diffraction grating must be of he same order of magnitude as the wavelength of the light.

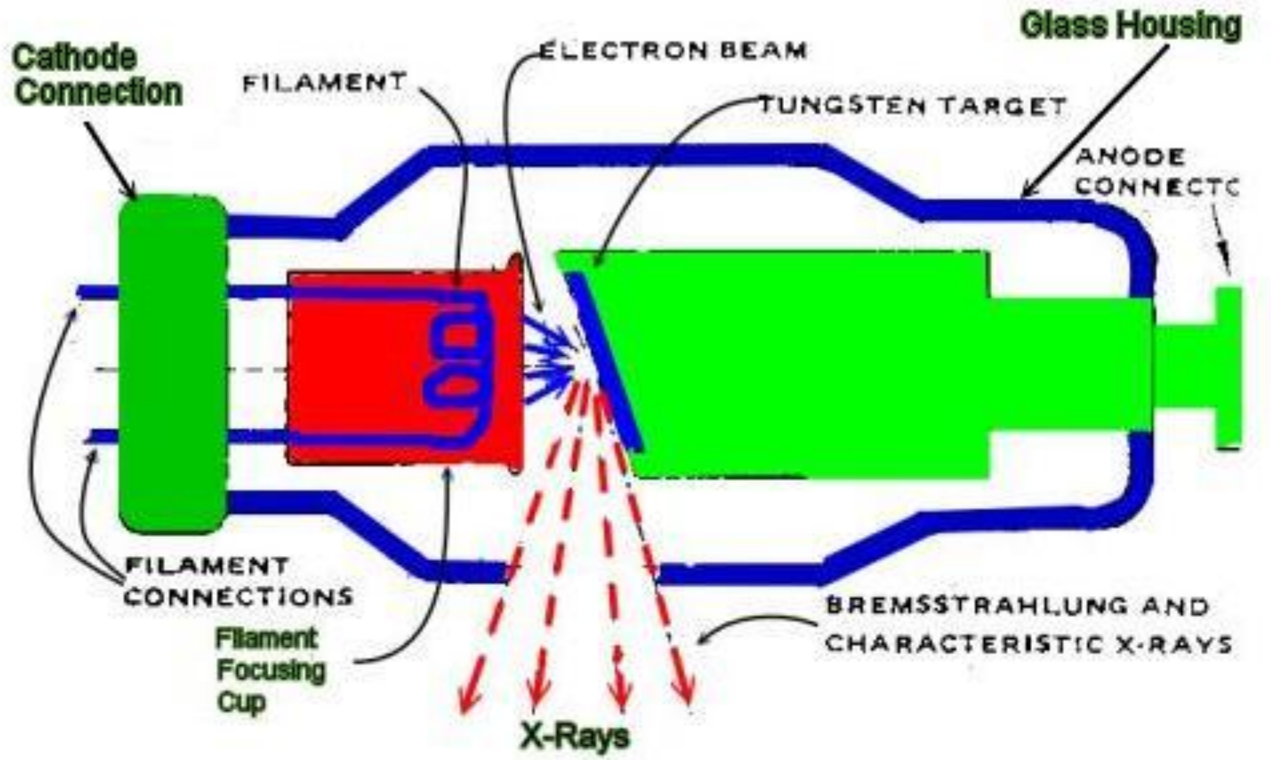
• Max von Laue realized that the wavelengths of X-rays are comparable to the spacing between adjacent atoms in crystals.

• X-ray wavelengths were from 0.01 nm to 10 nm.

• X-ray quanta are 10^4 times more energetic than visible light.

X-Rays

How are X-rays generated?

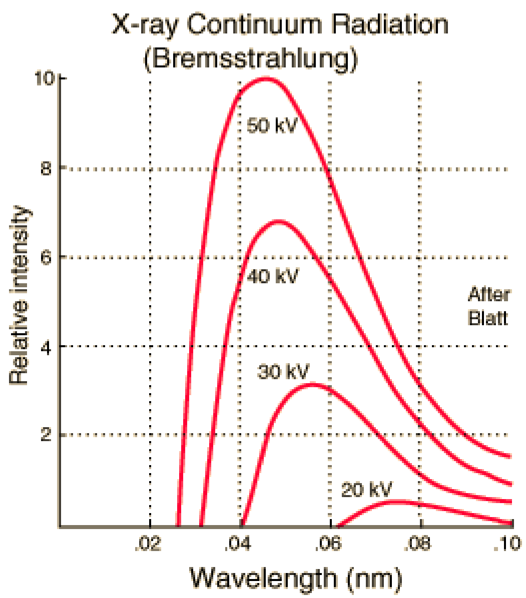


What does the radiation distribution looks like?

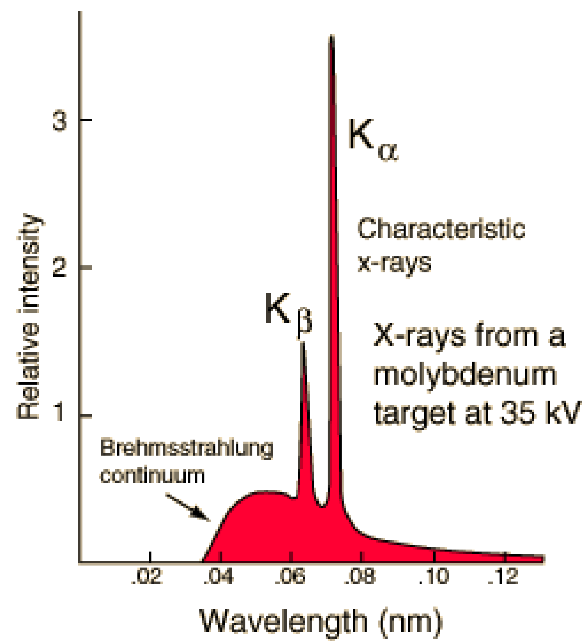
X-Rays

Relative intensity vs. wavelength…

Tungsten



Molybdenum



The curves exhibit two features that electromagnetic theory cannot explain!

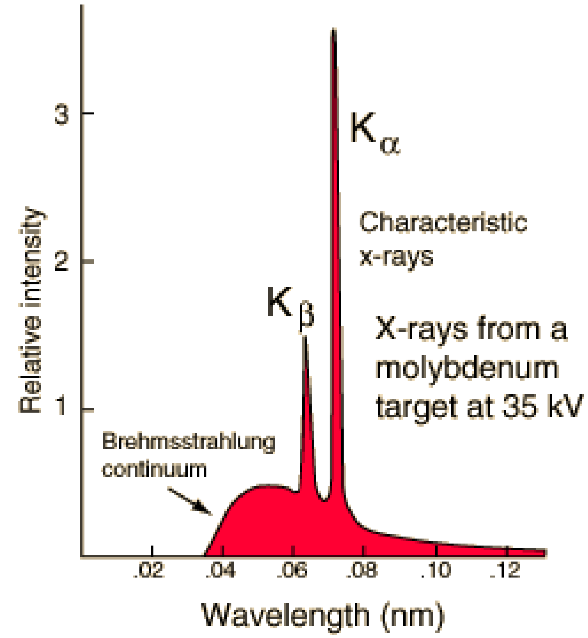
X-Rays

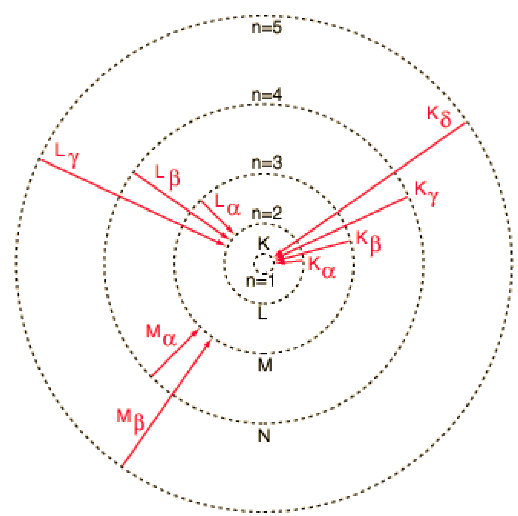
Characteristic X-ray...

• Intensity peaks indicate enhanced production of X-rays at certain wavelengths.

• These peaks occur at specific wavelengths for each target material

• They originate from the electron structure of the target atoms after being disturbed by the bombarding electrons.



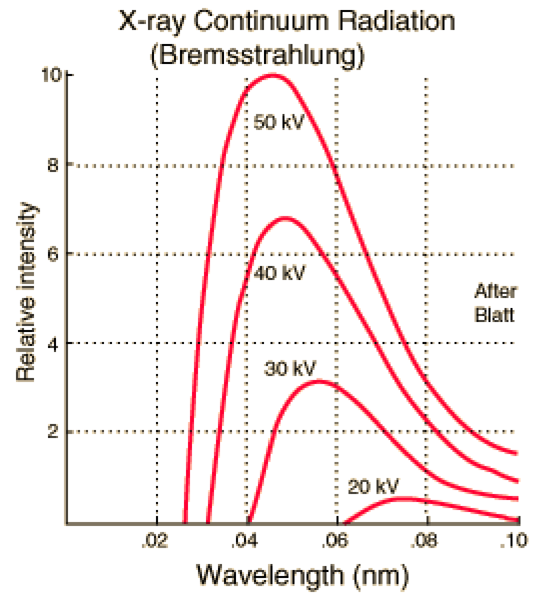


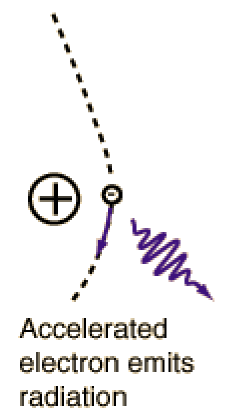
X-Rays

Continuous X-ray (Bremsstrahlung)…

- Wavelength vary with potential V.
- No wavelength is shorter than a λ_{min}.
- Increasing V decreases λ_{min}.
- $$\lambda_{min} = \frac{1.24\times10^{-6}}{V}$$

- Bremsstrahlung is the inverse photoelectric effect.





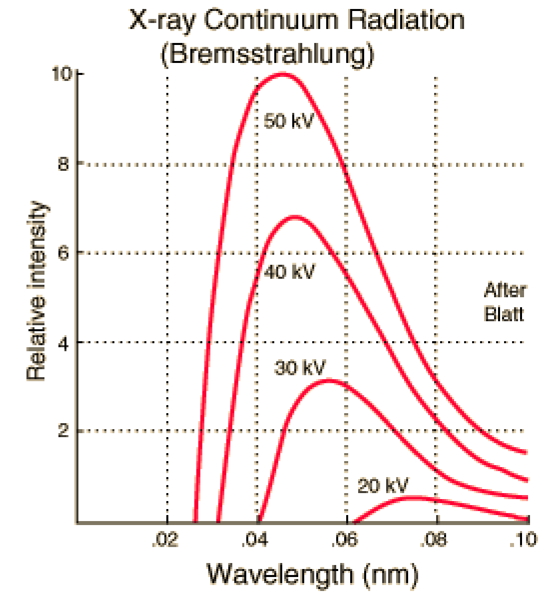
X-Rays

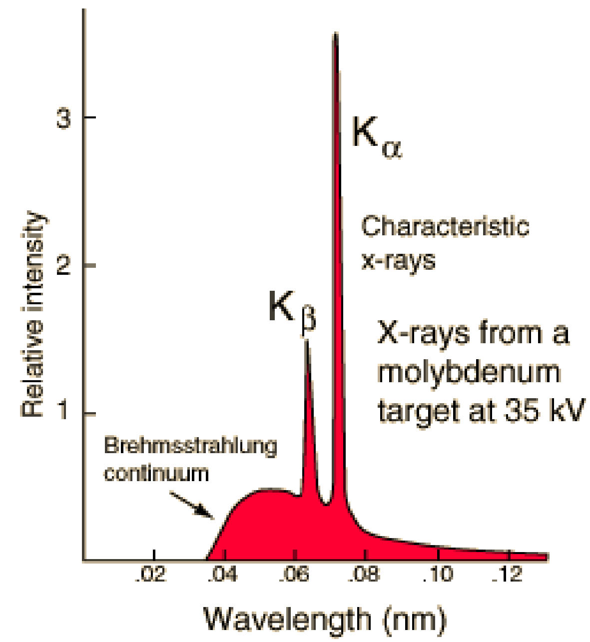
→ Since work functions are only few eV whereas the accelerating potential in X-ray tubes are ~ 10 - 100 of thousands of Volts, we can ignore the work function.

→ The short wavelength limit then corresponds to the entire KE = eV and is entirely given up to a single photon of energy $h\nu_{max}$.

$$Ve = h\nu_{max} = \frac{hc}{\lambda_{min}}$$

$$\lambda_{min} = \frac{hc}{Ve} = \frac{1.24\times10^{-6}}{V}$$





X-Rays

Example 2.3:

Find the shortest wavelength present in the radiation from an X-ray machine whose accelerating potential is 50,000 V.

X-Rays

Remember....

X-rays consist of high-energy photos...