De Broglie and his Matter Waves

POS Checklist:

(technically found under Unit D, but will be tested in Unit C)

- ☐ explain, qualitatively, how electron diffraction provides experimental support for the de Broglie hypothesis

- ☐ describe, qualitatively, how the two-slit electron interference experiment shows that quantum systems, like photons and electrons, may be modelled as particles or waves, contrary to intuition.

Diploma Question Alert!

Use the following information to answer the next question.

Selected Regions of the Electromagnetic Spectrum

I	television
II	AM radio
III	gamma radiation
IV	ultraviolet light
V	visible light

19. When the regions of the electromagnetic spectrum listed above are arranged in order of increasing wavelength, this order is

A. III, I, V, II, IV

B. II, I, V, IV, III

C. III, IV, V, I, II

D. IV, V, III, I, II

Diploma Question Alert!

23. The threshold frequency of light for the emission of photoelectrons from a metal is 4.4×10^{14} Hz. If light of frequency 6.6×10^{14} Hz shines on the metal, then the maximum kinetic energy of the emitted photoelectrons is

A. 7.3×10^{-19} J

B. 4.4×10^{-19} J

C. 2.9×10^{-19} J

D. 1.5×10^{-19} J

Diploma Question Alert!

25. The highest X-ray frequency that can be produced by an X-ray tube operating at 6.5×10^4 V is

A. 6.4×10^{-20} Hz

B. 1.0×10^{-14} Hz

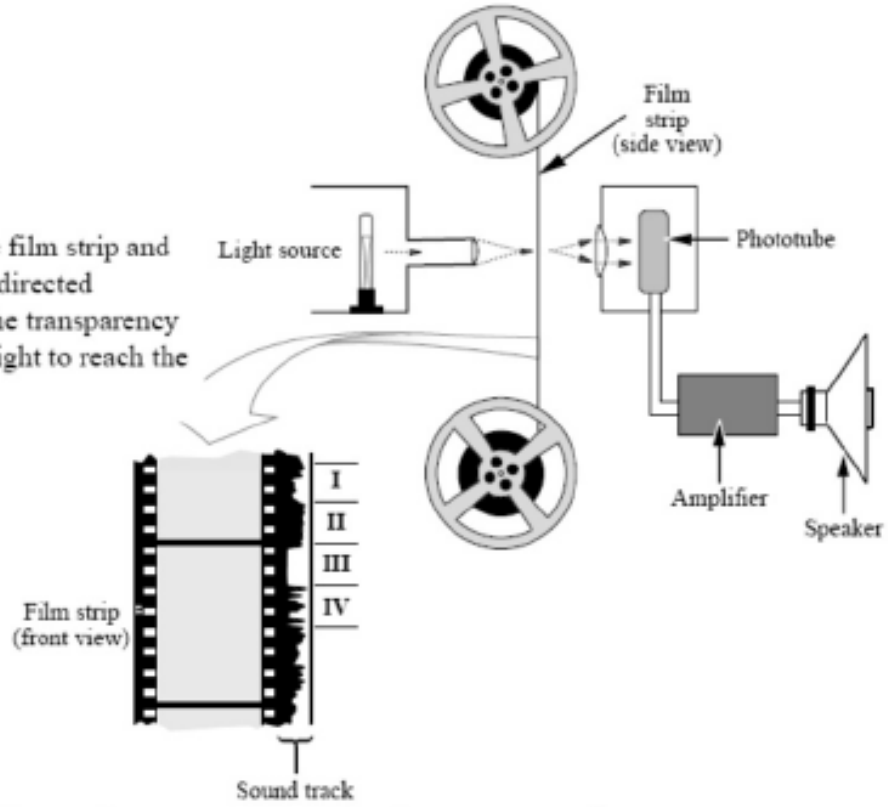
C. 1.6×10^{19} Hz

D. 3.2×10^{19} Hz

Diploma Question Alert!

An Application of the Photoelectric Effect

On movie film, the sound track is located along the side of the film strip and consists of light and dark regions. Light from the projector is directed through the sound track and onto a phototube. Variations in the transparency of the regions on the sound track allow varying intensities of light to reach the phototube.



26. The region of the sound track that will allow the most electrical current to be produced in the phototube is labelled

A. I

B. II

C. III

D. IV

Diploma Question Alert! (continued from last stem)

27. The energy that is required to remove the electron from the photoelectric surface in the phototube is called the

A. work function
B. threshold frequency
C. electric potential energy
D. maximum kinetic energy

Numerical Response

7. In one second, 1.45×10^{16} photons are incident on the phototube. If each of the photons has a frequency greater than the threshold frequency, then the maximum current to the amplifier, expressed in scientific notation, is $a.bc \times 10^{-d}$ A. The values of a, b, c, and d are _____ , _____ , _____ , and _____ .

(Record your **four-digit answer** in the numerical-response section on the answer sheet.)

Diploma Question Alert!

Use the following information to answer the next question.

Electron microscopes use the wave nature of electrons to detect objects that are too small to see with visible light. In order to detect an object, the wavelength used must be the same size or smaller than the object.

The momentum of a particle is related to its wavelength by the formula $p = \frac{h}{\lambda}$.

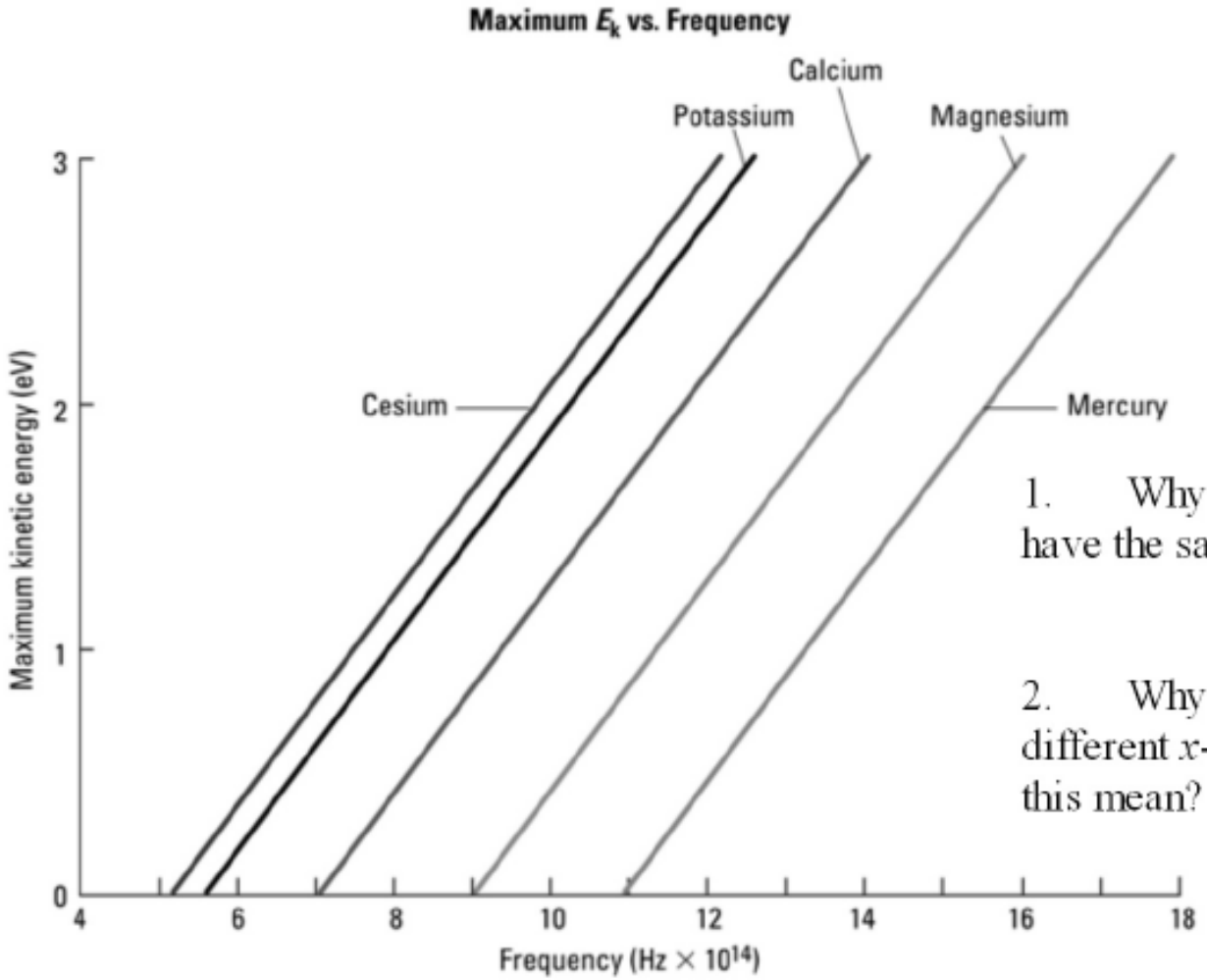
Important medical breakthroughs have resulted from viewing viruses that are 5.00×10^{-9} m in diameter.

Numerical Response

8. In order for a virus to be detected by an electron microscope, the minimum speed that the electrons must have in the electron microscope, expressed in scientific notation, is $b \times 10^{w}$ m/s. The value of b is _____.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Diploma Style Question Alert!



1. Why do all these graphs have the same slope?

2. Why do these graphs have different x-intercepts? What does this mean?

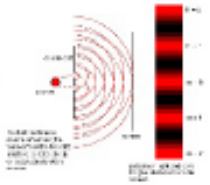
Is light a particle or a wave?

So, we've been through most of the unit, and we've collected evidence about whether light is a particle or a wave: let's recap:

Wave Properties

- Huygen's wavelets theory

- Young's Double-Slit Experiment



- Maxwell's EMR theory

Particle Properties

- Newton's explanation of reflection (and kind of refraction)

- Planck and quantization

- Einstein and photoelectric effect

- Compton Effect

So by as late as 1924, the wave-particle question still remained.

So the answer seemed quite obvious:

Is it a lion or a tiger?

It's Both.

We say light exibits a wave-particle duality: in some situations, it behaves like a wave, in others, like a particle.

But is this idea limited to only photons? Why can't it extend to all matter?

Enter: Louis de Broglie

- proposed all matter exhibited a wave-particle duality

- the wavelength of matter is so small, we can not detect it easily

- very small bits of matter (like electrons) will exhibit these wave properties

De Broglie began by suggesting only moving particles had a wavelength, so let's start there with an equation derivation:

According to Einstein:

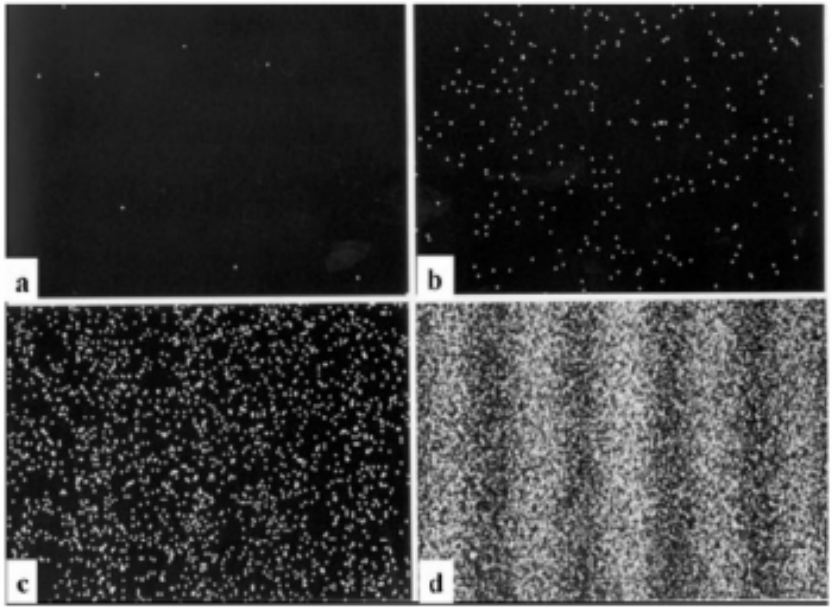
$$p = \frac{h}{\lambda}$$

momentum of a photon

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

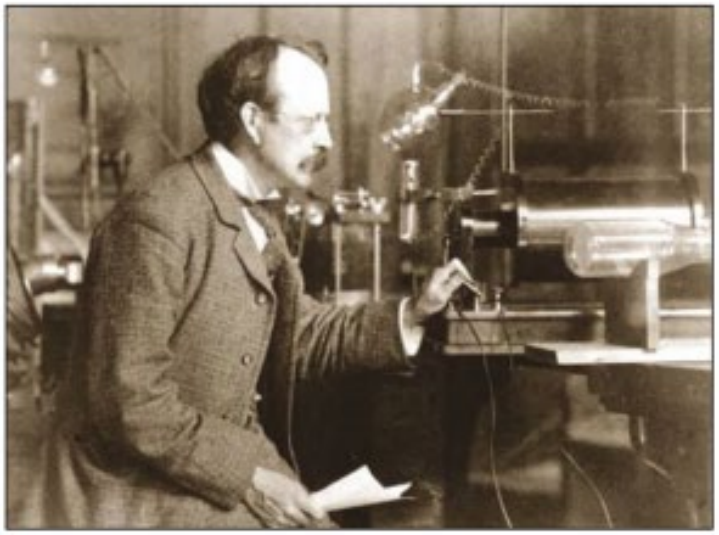
wavelength of a particle

The idea that matter behaves like a wave seemed far out, but was accepted by Einstein and tested experimentally with using a double slit apparatus like Young's and electrons.



After enough electrons were passed through the double slit, definite areas of constructive and destructive interference were observed.

Some of these double slit experiments were performed by G.P. Thompson, son of J.J. Thompson (gold-foil experiment and discovery of electron).



J.J.

G.P.

So, J.J. discovered that the electron was a particle, and his son proved it behaved like a wave.

Practice Calculations:

Find the wavelength of an electron that has an energy of 3.10×10^{6} J.

Find the speed of an electron with a wavelength of 700 nm.

What is the wavelength of a ball of mass 1.30 kg and a speed of 3.2 m/s?