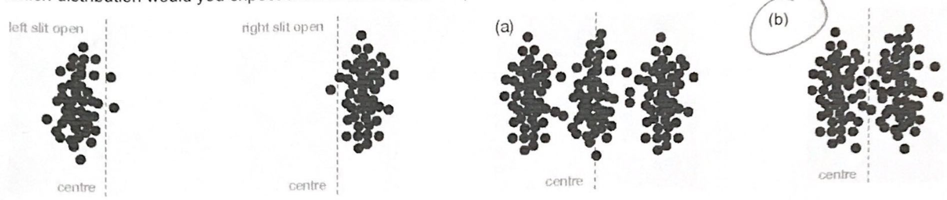
$\Delta x = \frac{\lambda L}{d}$ $\lambda = \frac{h}{p} = \frac{h}{mv}$ $E = hf$ $V = \frac{E_Q}{q}$ $E_K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

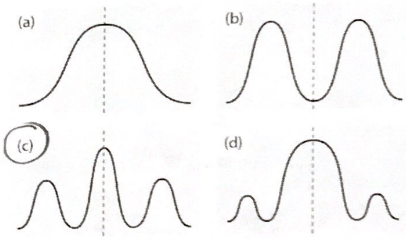
$m_e = 9.11 \times 10^{-31}$ kg $c = 3.00 \times 10^8$ m/s $h = 6.626 \times 10^{-34}$ J·s $q_e = 1.602 \times 10^{-19}$ C 1 amu = 1.6605×10^{-27} kg

01. Tennis balls are sent toward two slits. The distributions of the marks they make on the wall on the other side of the barrier when one slit is open are below.
Which distribution would you expect to see if both slits are open at the same time?



02. Which statement correctly describes how waves behave when they occupy the same location at the same time?
(a) A crest overlapping with a crest will constructively interfere to produce a minima.
(b) A crest overlapping with a trough will constructively interfere to produce a minima.
(c) A trough overlapping with a trough will constructively interfere to produce a maxima.
(d) A trough overlapping with a trough will destructively interfere to produce a maxima.

03. A water wave passes through two slits. Which pattern best matches the amplitude of the resulting wave?



04. Classical particles are different from classical waves because classical particles
(a) are spread out and generate an interference pattern in the double-slit experiment.
(b) are localized and generate an interference pattern in the double-slit experiment.
(c) are localized and generate a distribution that is the sum of each single-slit distribution.
(d) are spread out and generate a distribution that is the sum of each single-slit distribution.

05. The video shows the interference of light of a single colour. What would you expect if white light were used?
(a) bands of white light and darkness
(b) bands of different colours of light and darkness
(c) a white central maxima and alternating bands of different colours of light and darkness on either side
(d) no interference pattern

06. To better understand the double-slit experiment, it was important to send electrons through one slit at a time because
(a) the detector needed time to reset in order to detect the next electron.
(b) the slits were too narrow to allow two electrons to pass at the same time.
(c) this prevented the electrons from interacting with one another.
(d) time is needed to generate more electrons.

07. In the double-slit experiment, electrons
(a) behave like waves and behave like particles.
(b) split in half and go through both slits simultaneously.
(c) behave like particles, but are waves.
(d) are both waves and particles at the same time.

Actual image from the electron double-slit experiment

08. You get sunburn from ultraviolet light but not from visible light. This is because UV photons have a greater
(a) mass.
(b) frequency.
(c) speed.
(d) wavelength.

09. Why have interference effects with tennis balls not been observed?

(a) The de Broglie wavelength equation, $\lambda = h/p$ is only for sub-microscopic objects.
(b) The experiment has not been done yet.
(c) The de Broglie wavelength for a tennis ball will be much smaller than for an atom.
(d) The de Broglie wavelength for a tennis ball will be larger than for an atom.

10. All quantum objects exhibit wave-particle duality. In the double-slit experiment this is shown by the fact that individual objects hit the screen

(a) at specific locations and build up an interference pattern after a large number have hit.
(b) in a spread-out way and build up an interference pattern after a large number have hit.
(c) at specific locations and build up a particle distribution after a large number have hit.
(d) in a spread-out way and build up a particle distribution after a large number have hit.

11. If we do measurements to determine which slit an electron went through, we find that

(a) half of the electron goes through each slit.
(b) the whole electron goes through both slits.
(c) the whole electron goes through one or the other slit.
(d) it is impossible to detect an electron.

12. With electrons in the double-slit experiment, physicists know

(a) where an electron will hit the screen.
(b) which slit the electron went through, without the aid of a detector.
(c) that the electron went through both slits.
(d) that all of the interpretations give the same predictions for the overall results.

13. There are competing ideas about what is actually happening between the source and the detector in the double-slit experiment. In which of the interpretations does a single electron go through one and only one slit?

(a) Pilot Wave and Collapse
(b) Pilot Wave and Many Worlds
(c) Collapse and Many Worlds
(d) Pilot Wave, Collapse, and Many Worlds

14. An electron microscope can produce clearer images of significantly smaller objects than a light microscope can because the electrons have a

(a) larger frequency.
(b) smaller size.
(c) slower speed.
(d) shorter wavelength.

$v = f \cdot \lambda$

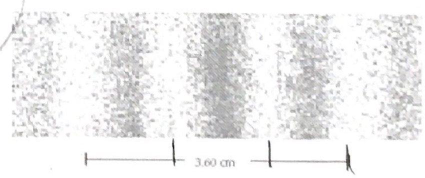
$3 \times 10^8 =$

15. Which quantum application has had the greatest effect on your life?

(a) solar panels
(b) transistors
(c) lasers
(d) other

any

16. The photo below shows the interference pattern produced by an electron double-slit experiment. In this experiment, the electrons were sent through a double-slit apparatus with an effective slit separation of 200 nm. The detector screen was 79.0 cm from the double slits. The image has been **magnified by a factor of 100**.



(a) Use Young's double-slit equation to determine the wavelength of the electron.

$\Delta x = \frac{L\lambda}{d}$ $\quad \lambda = \frac{\Delta x \cdot d}{L}$ $\quad \lambda = \frac{(0.012 \times 10^{-2})(200 \times 10^{-9})}{(0.79)}$

$\lambda = 3.038 \times 10^{-11} m$

(b) Use the de Broglie wavelength equation to determine the momentum and velocity for the electrons passing through the apparatus.

$\lambda = \frac{h}{p}$ $\quad p = \frac{6.626 \times 10^{-34}}{3.038 \times 10^{-11}}$ $\quad p = 2.181 \times 10^{-23} \frac{kg \cdot m}{s}$ $\quad v = 2.39 \times 10^7 m/s$

$\frac{\left(\frac{3.60 cm}{100}\right)}{3} = \Delta x = 0.012 cm$

(c) The electrons were accelerated by an electric field. Calculate the potential difference needed to produce these results.

$V = \frac{E_k}{q}$ $\quad V = \frac{p^2}{q 2m}$ $\quad V = \frac{(2.181 \times 10^{-23})^2}{(1.602 \times 10^{-19})(2)(9.11 \times 10^{-31})}$ $\quad V = 1630$ volts

Multiple Choice Answers (use capitals please)

1.	2.	3.	4.	5.	6.	7.	8.
B	C	C	C	C	C	A	B
9.	10.	11.	12.	13.	14.	15.	
C	A	C	D	B	D	ANY	