Checkpoints Chapter 16
Wave Properties of Matter

Question 693

The momentum of the x-rays is equal to the momentum of the electrons.

Momentum of the proton is given by $p = \frac{h}{\lambda}$

$\therefore h = p \times \lambda$
$= 7.94 \times 10^{-25} \times 8.35 \times 10^{-10}$
$= 6.63 \times 10^{-34}$
6.63×10^{-34} Js (ANS)

Question 694

To produce the same diffraction pattern the ratio $\frac{\lambda}{d}$ must be the same. And since $\lambda = \frac{h}{p}$ (de Bröglie wavelength) then for λ to be the same, both must have the same momentum (p).

Question 695

For the 'particle' to show wave behaviour when fired at a thin layer of the crystal, it must diffract as it passes through the atoms of the crystal. When it diffracts it will then show interference effects. It will only diffract if the ratio of $\frac{\lambda}{d}$ is approximately 1.

Partial diffraction occurs when $\frac{\lambda}{d}$ is between about 0.1 and 1.

So this question wants you to find the three different wavelengths and then find the ratio $\frac{\lambda}{d}$, or find the wavelength closest to the crystal spacing of 3 x 10^{-9} m.

A

60eV electron has a KE of $1.6 \times 10^{-19} \times 60$
$= 9.6 \times 10^{-18}$ J
$\therefore \frac{1}{2}mv^2 = 9.6 \times 10^{-18}$
$\therefore v^2 = 2 \times 9.6 \times 10^{-18} \div 9.1 \times 10^{-31}$
$\therefore v^2 = 2.1 \times 10^{13}$
$\therefore v = 4.6 \times 10^6$ m/s.

since $\lambda = \frac{h}{p}$ ((de Bröglie wavelength)

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

$= \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 4.6 \times 10^{6}}$
$= 1.56 \times 10^{-10}$ m.

B

X-rays travel at the speed of light, so v= fλ becomes

$c = f\lambda$
$\therefore \lambda = c \div f$
$\therefore \lambda = 3 \times 10^8 \div 10^{19}$
$\therefore \lambda = 3 \times 10^{-11}$ m.

C

Since $\lambda = \frac{h}{p}$ (de Bröglie wavelength)

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

$= \frac{6.63 \times 10^{-34}}{1.0 \times 10^{-6} \times 0.01}$
$= 6.63 \times 10^{-26}$ m.

$\therefore$ **A (ANS)**

Question 696

The momentum of the electron

$p = m \times v$
$= 9.1 \times 10^{-31} \times 1.78 \times 10^7$
$= 1.62 \times 10^{-23}$

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

$\therefore \lambda = \frac{6.63 \times 10^{-34}}{1.62 \times 10^{-23}}$

$\therefore$ **4.1×10^{-11} m (ANS)**

Question 697

120 pm = 1.2×10^{-10}m.

This makes the gap to be about 3 times the wavelength. The amount of diffraction is $\propto \frac{\lambda}{w}$.

$\therefore \frac{\lambda}{w} \approx 0.3$.

There is complete diffraction when $\frac{\lambda}{w} \geq 1$.

There will be significant diffraction when $\frac{\lambda}{w} > 0.1$

$\therefore$ **Yes (ANS)**

Question 698

As the pattern remains the same, the momentum of the X-rays must be the same as the momentum of the electron.
The momentum of the X-rays is given by

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

$$\therefore p = \frac{6.63 \times 10^{-34}}{56 \times 10^{-12}}$$

$\therefore$ p = 1.184×10^{-23}

Therefore the momentum of the electrons is the same.

$\therefore$ p = 1.2×10^{-23} Ns (ANS)

Question 699

The ratio $\frac{\lambda}{d}$ describes the amount of diffraction.

When $\frac{\lambda}{d}$ ~1, then there is complete diffraction, i.e. bending of 180^0 (half circle).

The smaller $\frac{\lambda}{d}$ is then the less diffraction.

A $\frac{\lambda}{d} = \frac{500 \times 10^{-9}}{0.05 \times 10^{-3}} = 0.01$

B The momentum of the electron
= m × v
= $9.1 \times 10^{-31} \times 5 \times 10^{6}$
= 4.55×10^{-24} Ns

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

but $\frac{\lambda}{d} = \frac{h}{p.d}$

$$= \frac{6.63 \times 10^{-34}}{4.55 \times 10^{-24} \times 0.00015 \times 10^{-3}}$$

= 0.001.

$\therefore$ A (ANS)

Question 700 (2010 Q7, 2m, 65%)

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

$$= \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.5 \times 10^{7}}$$

= 4.856×10^{-11}
= $4.9 \times 10^{-2} \times 10^{-9}$
= 0.049 nm (ANS)

Question 701 (2010 Q8, 2m, 50%)

Increasing the accelerating voltage will increase the speed of the electrons. This will increase their momentum.

From $\lambda = \frac{h}{mv}$ increasing the momentum will decrease the deBroglie wavelength of the electrons.

The amount of diffraction (bending) is given by $\frac{\lambda}{w}$, so the smaller wavelength means smaller spacing between diffraction lines.

$\therefore$ A (ANS)

Question 702 (2010 Q9, 2m, 60%)

The spacing of the pattern depends on the wavelength. Both the X-rays and the electrons will produce very similar diffraction patterns because they have very similar (or the same) wavelengths. This is one of those questions where less is better. A lot of students wrote very long answers and lost marks due to incorrect statements.

Question 703 (2010 Q10, 3m, 20%)

The wavelength of the X-rays is the same as the wavelength of the electrons. To find the wavelength of the electrons use your answer to the first question in this set. Or

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

$$= \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.5 \times 10^{7}}$$

= 4.857×10^{-11}
= 0.049 nm

Then for the X-ray use $E = \frac{hc}{\lambda}$,

$$\therefore E = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{4.9 \times 10^{-11}}$$

= 2.53×10^{4}

So energy is 25.3 keV. (ANS)

I'm not sure why the examiner got an answer of 2.48×10^{4} eV. This used the **rounded off** value of 0.05 nm for the wavelength. From a significant figure perspective, I think that you are justified in using 0.049 nm.

Question 704 (2011 Q10, 2m, 75%)

For an X-ray use $E = \frac{hc}{\lambda}$,

$$\therefore E = \frac{4.14\times10^{-15}\times3\times10^{8}}{0.2\times10^{-9}}$$

$= 6.210 \times 10^3$

$= 6.21 \times 10^3$ eV (ANS)

Question 705 (2011 Q11, 2m, 25%)

If the diffraction pattern is similar for both the electrons and the photons, then the electrons need to have the same wavelength (hence momentum) as the photons.

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

$\therefore p = \frac{6.63\times10^{-34}}{0.2\times10^{-9}}$

$\therefore p = 3.315 \times 10^{-24}$

Use $E = \frac{p^2}{2m}$

$\therefore E = \frac{(3.315\times10^{-24})^2}{2\times9.1\times10^{-31}}$

$\therefore E = 0.604 \times 10^{17}$

To convert into eV divide by 1.6×10^{-19}

$\therefore E = 0.377 \times 10^2$

$\therefore$ E = 38 eV (ANS)

Question 706 (2011 Q12, 2m, 65%)

Electrons behave exhibit wavelike properties and have a wavelength.
The spacing of the diffraction pattern is a property of the wavelength of the light/particles.
Since the X-rays have the same wavelength of the electrons they will both have the same diffraction pattern.

Question 707 (2012 Q3a, 2m, 60%)

KE $= \frac{1}{2}mv^2$

$= \frac{1}{2} \times 9.1 \times 10^{-31} \times (1.5 \times 10^5)^2$

$= 1.024$ J

Convert into eV by dividing by 1.6×10^{-19}

$\therefore$ KE = 0.064 eV (ANS)

Question 718 (2012 Q3b, 2m, 60%)

As the pattern remains the same, the momentum of the photon must be the same as the momentum of the electron.

$p_{electron} = mv$

$= 9.1 \times 10^{-31} \times 1.5 \times 10^5$

$= 1.365 \times 10^{-25}$.

For the photon, E = pc

$\therefore E = 4.095 \times 10^{-17}$ J

Convert to eV by dividing by 1.6×10^{-19}

$\therefore$ E = 256 eV (ANS)

Question 709 (2013 Q23a, 2m, 36%)

Use E (in joules) = pc,

$\therefore p = \frac{E}{c}$

$\therefore p = \frac{80000\times1.6\times10^{-19}}{3\times10^{8}}$

$\therefore p = 4.3 \times 10^{-23}$ kg m s^{-1} (ANS)

An alternative method is using $E = \frac{hc}{\lambda}$,

to get $\lambda = 1.55 \times 10^{-11}$ m,

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

$\therefore p = \frac{6.63\times10^{-34}}{1.55\times10^{-11}}$

$\therefore p = 4.3 \times 10^{-23}$ kg m s^{-1} (ANS)

Question 710 (2013 Q23b, 3m, 38%)

The first mark was allocated to;
A is correct

To gain full marks you also needed to say:
(i) fringe spacing depends on wavelength
ii) wavelength depends on momentum.

Question 711 (2014 Q21d, 3m, 33%)

The spacing of the lines in the diffraction pattern depends on the ratio $\frac{\lambda}{d}$.

Both beams are incident on the same aperture, so 'd' is constant. Therefore the pattern depends on λ. If the patterns are different then the electrons and X-rays have different wavelengths.

Since $p = \frac{h}{\lambda}$, then they both have different momentums.

For an electron $E = \frac{p^2}{2m}$, and for a photon E = pc.

If they have the same energy, then they will have different momentums.