Past-paper walk-through

Compton Scattering ▪ 15.6

eXercise

Questions in this set

- 2021 Q4

Reading the mark scheme

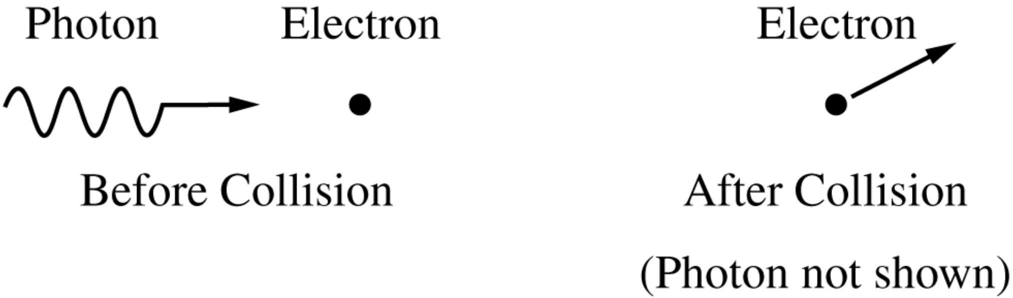
- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = “or words to that effect” – the wording need not match.

Question 4

2021 ▪ Q4

Light and matter can be modeled as waves or as particles. Some phenomena can be explained using the wave model, and others can be explained using the particle model.
(a) Calculate the speed, in m/s, of an electron that has a wavelength of 5.0 nm.

Question 4


Photon
Electron
Before Collision
Electron
After Collision
(Photon not shown)

Question 4

2021 ▪ Q4

Light and matter can be modeled as waves or as particles. Some phenomena can be explained using the wave model, and others can be explained using the particle model.

(b) The electron is moving with the speed calculated in part (a) when it collides with a positron that is at rest. A positron is a particle identical to an electron except that its charge is positive. The two particles annihilate each other, producing photons. Calculate the total energy of the photons.

Question 4

2021 ▪ Q4

Light and matter can be modeled as waves or as particles. Some phenomena can be explained using the wave model, and others can be explained using the particle model.

(c) [Diagram: on the left, a wavy arrow labeled “Photon” moving right toward a dot labeled “Electron”, captioned “Before Collision”. On the right, a dot labeled “Electron” with a straight arrow pointing up and to the right, captioned “After Collision (Photon not shown)”.]

A photon approaches an electron at rest, as shown above on the left, and collides elastically with the electron. After the collision, the electron moves toward the top of the page and to the right, as shown above on the right, at a known speed and angle. In a coherent, paragraph-length response, indicate a possible direction for the photon that exists after the collision and its frequency compared to that of the original photon.

Question 4

Describe the application of physics principles that can be used to determine the direction of motion and frequency of the photon that exists after the collision.

Solution 4

(a)

Mark scheme

- Using the de Broglie relation = h/p = h/(mv), solve for speed: v = h/(m) = (6.63×10^-34 J · s) / [(9.11×10^-31 kg)(5.0×10^-9 m)] = 1.5×10^5 m/s. Award 1 point for the correct relationship (=h/mv, rearranged for v) and 1 point for correctly substituting the given values (m_e = 9.11×10^-31 kg, = 5.0×10^-9 m, h = 6.63×10^-34 J · s).

Solution 4

(b) Mark scheme

- Using $E=mc^2$ to convert the rest masses of the electron and positron to energy (1 point), and including the kinetic energy of the moving electron (1 point), with a speed consistent with part (a) and correct substitutions (1 point): E_tot = 2(9.11×10^-31 kg)(3×10^8 m/s)^2 + (1/2)(9.11×10^-31 kg)(1.5×10^5 m/s)^2 = 1.6×10^-13 J. (The at-rest positron contributes only its rest energy mc^2; the moving electron contributes its rest energy mc^2 plus its kinetic energy $(1/2)mv^2$, using v from part (a); both particles' total energy converts entirely into photon energy upon annihilation.)

Solution 4

(c) Mark scheme

- A complete paragraph argument should establish: (1) since the electron moves up and to the right after the collision, to conserve momentum in the vertical direction the outgoing photon must carry a component of momentum (or velocity) toward the BOTTOM of the page (1 point); (2) momentum must be conserved separately in both the horizontal and vertical directions (1 point); (3) energy must also be conserved in the collision (1 point); (4) because some of the photon's energy is transferred to the electron (which gains kinetic energy), the outgoing photon has LESS energy than the incoming photon and therefore a LOWER frequency, via $E=hf$ (1 point); (5) the response overall is logical, relevant, internally consistent, addresses the question asked, and follows the paragraph-response format

Solution 4

requirements (1 point). Example: 'In order to conserve momentum in the vertical direction, the photon must have a component of its momentum toward the bottom of the page. If the horizontal component of the momentum of the electron after the collision is less than the initial momentum of the photon, then the photon must move toward the right after the interaction. In order to conserve energy, the frequency of the photon after the collision is less than what it was before the collision because it gave some of its energy to the electron.'