

Question 4: Short Answer Paragraph Argument**10 points**

(a)	For obtaining the correct relationship between electron wavelength and speed	1 point
	For correctly substituting values	1 point

Example response for part (a)

$$\lambda = h/p = h/mv$$

$$v = \frac{(6.63 \times 10^{-34} \text{ J}\cdot\text{s})}{(9.11 \times 10^{-31} \text{ kg})(5.0 \times 10^{-9} \text{ m})}$$

$$v = 1.5 \times 10^5 \text{ m/s}$$

Total for part (a) 2 points

(b)	For using $E = mc^2$ to convert mass to energy	1 point
	For including the kinetic energy of the electron	1 point
	For including the equivalent energy of both particles and correct substitutions, with a speed consistent with the answer to part (a)	1 point

Example response for part (b)

$$E_{tot} = 2(9.11 \times 10^{-31} \text{ kg})(3 \times 10^8 \text{ m/s})^2 + (1/2)(9.11 \times 10^{-31} \text{ kg})(1.5 \times 10^5 \text{ m/s})^2$$

$$E_{tot} = 1.6 \times 10^{-13} \text{ J}$$

Total for part (b) 3 points

(c)	For indicating that the photon has a component of momentum (or velocity) toward the bottom of the page	1 point
	For indicating that momentum must be conserved in both the horizontal and vertical directions	1 point
	For indicating that energy is conserved	1 point
	For indicating that the new photon has less energy, so it has a lower frequency	1 point
	For a logical, relevant, and internally consistent argument that addresses the required argument or question asked and follows the guidelines described in the published requirements for the paragraph-length response	1 point

Example response for part (c)

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.

Total for part (c) 5 points**Total for question 4 10 points**