**28.** (I) A high-frequency photon is scattered off of an electron and experiences a change of wavelength of 1.5 X 10-4 nm . At what angle must a detector be placed to detect the scattered photon (relative to the direction of the incoming photon)?

28. We use Eq. 37-6b. Note that the answer is correct to two significant figures.



**29.** (II) Determine the Compton wavelength for (*a*) an electron, (*b*) a proton. (*c*) Show that if a photon has wavelength equal to the Compton wavelength of a particle, the photon’s energy is equal to the rest energy of the particle.

29. The Compton wavelength for a particle of mass *m* is 

(*a*) 

(*b*) 

(*c*) The energy of the photon is given by Eq. 37-3.



**30.** (II) X-rays of wavelength λ=0.120nm are scattered from carbon. What is the expected Compton wavelength shift for photons detected at angles (relative to the incident beam) of exactly (*a*) 60°, (*b*) 90°, (*c*) 180°?

30. We find the Compton wavelength shift for a photon scattered from an electron, using Eq. 37-6b. The Compton wavelength of a free electron is given in the text right after Eq. 37-6b.



(*a*) 

(*b*) 

(*c*) 

**31.** (II) In the Compton effect, determine the ratio (Δλ/λ) of the maximum change Δλ in a photon’s wavelength to the photon’s initial wavelength λ, if the photon is (*a*) a visible-light photon with λ=550nm (*b*) an X-ray photon with λ=0.10nm.

31. (*a*) In the Compton effect, the maximum change in the photon’s wavelength is when scattering angle . We use Eq. 37-6b to determine the maximum change in wavelength. Dividing the maximum change by the initial wavelength gives the maximum fractional change.



(*b*) We replace the initial wavelength with 



**32.** (II) A 1.0-MeV gamma-ray photon undergoes a sequence of Compton-scattering events. If the photon is scattered at an angle of 0.50° in each event, estimate the number of events required to convert the photon into a visible-light photon with wavelength 555 nm. You can use an expansion for small θ; [Gamma rays created near the center of the Sun are transformed to visible wavelengths as they travel to the Sun’s surface through a sequence of small-angle Compton scattering events.]

32. We find the change in wavelength for each scattering event using Eq. 37-6b, with a scattering angle of  To calculate the total change in wavelength, we subtract the initial wavelength, obtained from the initial energy, from the final wavelength. We divide the change in wavelength by the wavelength change from each event to determine the number of scattering events.



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**Pair Production**

**35.** (I) How much total kinetic energy will an electron–positron pair have if produced by a 2.67-MeV photon?

35. The photon energy must be equal to the kinetic energy of the products plus the mass energy of the products. The mass of the positron is equal to the mass of the electron.



**36.** (II) What is the longest wavelength photon that could produce a proton–antiproton pair? (Each has a mass of 1.67X10-27kg)

36. The photon with the longest wavelength has the minimum energy in order to create the masses with no additional kinetic energy. Use Eq. 37-5.



This must take place in the presence of some other object in order for momentum to be conserved.

**37.** (II) What is the minimum photon energy needed to produce a μ + μ- pair? The mass of each μ (muon) is 207 times the mass of an electron. What is the wavelength of such a photon?

37. The minimum energy necessary is equal to the rest energy of the two muons.



The wavelength is given by Eq. 37-5.



**38.** (II) An electron and a positron, each moving at 2.0X105m/s collide head on, disappear, and produce two photons moving in opposite directions, each with the same energy and momentum. Determine the energy and momentum of each photon.

38. Since  the total energy of the particles is essentially equal to their rest energy. Both particles have the same rest energy of 0.511 MeV. Since the total momentum is 0, each photon must have half the available energy and equal momenta.



**39.** (II) A gamma-ray photon produces an electron and a positron, each with a kinetic energy of 375 keV. Determine the energy and wavelength of the photon.

39. The energy of the photon is equal to the total energy of the two particles produced. Both particles have the same kinetic energy and the same mass.



The wavelength is found from Eq. 37-5.

