Photons

What is the momenergy of a photon?

In an introductory physics course at the college level, we generally tell students the following information.

Light can sometimes be thought of as being made up of packets of energy called photons.

The energy of a photon is proportional to the frequency of the light: $E = hf$.

Photons have no mass.

Despite this, photons do have momentum. The magnitude of the momentum is given by

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

How should we think of a photon from a momenergy perspective? The photon still has to satisfy the equation $m^2 = E^2 - p^2$. What does this tell us about how the magnitude of the momentum of a photon compares to its energy?

Let's draw the momenergy vector for a photon traveling in the +x direction with an energy of 2 units. How should we label the handle on the momenergy?

Pair production is the name given to the process of a high-energy photon transforming into an electron-positron pair. In this case, let's take 1 mass unit to represent the mass of an electron (and a positron, which has the same mass). What is the absolute minimum amount of energy the photon must have to produce an electron-positron pair?

Can a photon of sufficient energy transform itself into an electron-positron pair in empty space? Would such a process satisfy the conservation laws? Sketch momenergy diagrams to either prove or disprove this possibility.

The **Compton effect** demonstrates quite clearly that (a) light can act is if it is made up of photons, and (b) that the photons carry momentum. The Compton effect is basically a collision involving a photon and an electron, with the electron being at rest before the collision. Let's consider the special case of the photon exactly reversing direction after the collision. We'll again use mass units such that the electron mass is 1 unit. The photon before the collision has 2 mass units worth of energy.

Draw momenergy vectors representing the photon, the electron, and the system before the collision.

What is the mass of the system before the collision?

If you can, determine what the energy and momentum of the photon is after the collision, and find the energy and momentum of the electron after the collision. One possible way to approach this (although it is not particularly elegant) is to fill in the table below until you find the one line that satisfies the conservation laws.

Photon E	Photon p	Electron E	Electron p	Electron m = $\sqrt{E^2 - p^2}$	Correct?
0	0	3	2	$\sqrt{5}$	No
0.1	-0.1				
0.2	-0.2				
0.3	-0.3				
0.4	-0.4				
0.5	-0.5				
0.6	-0.6				
0.7	-0.7				
0.8	-0.8				
0.9	-0.9				
1.0	-1.0	2.0	3.0	$-\sqrt{5}$	No

Sketch the momenergy vectors for the situation after the collision.