Do Accelerating Charged Particles Really Radiate?

Author: Singer, Michael
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eMail: singer43212@gmail.com

Abstract

In a particle accelerator charged particles radiate when they pass through beam-bending magnets that give them a centripetal acceleration. This is commonly put down to acceleration-induced radiation, but the fact that there are several different detailed theories to explain this phenomenon suggests that it is not well understood. In addition electrons orbiting a nucleus also have centripetal acceleration and do *not* radiate, so we have the problem that accelerating electrons radiate only sometimes. This suggests that it is not the acceleration per se that creates the radiation but some other factor that exists only in the beam-bending scenario. This paper goes further, and shows that the general concept of acceleration-induced radiation is a violation of the Principle of Conservation of Energy, so that in an energy-conserving universe another cause must be found for the radiation from accelerating charged particles where it occurs.

Radiation Generation from Accelerating Electric Charges

A historical background

The traditional theory is that when a charged particle accelerates it radiates electromagnetic energy. It has sometimes been claimed that there is a failure of Classical Electromagnetism in not being able to determine why an accelerating free electron radiates but a bound electron, in orbit around the nucleus of an atom and hence undergoing centripetal acceleration, does not. However, it is a failure of every model of the world that accepts that these two situations exist but cannot create a sound theory to support that difference. There are a number of different theories as to the generation of radiation under acceleration with no particular theory having a unanimous acceptance amongst scientists and this is an indicator that whatever is going on is not well understood.

The theory dates back to the discovery of X-Rays. At that time the model of the atom was the "plum-pudding" model of a solid lump with the electrons stuck into it. The idea was born that X-Rays were generated when high-speed electrons suddenly impacted on the "plum pudding" and stopped dead, radiating electromagnetic energy as a result of that extreme deceleration. Later on, with our modern model of a tiny nucleus surrounded by circling electrons, it was realised that the X-Rays were not born out of extreme deceleration, but by high-speed electrons diving deep into the atoms of the target metal and interacting with their electromagnetic fields. However, the theory was retained to account for radiation generated in particle accelerators.

An analytic thought experiment

We can summarise all such theories by the following generic "thought experiments". Let us analyse a simple case. An electron is accelerated by some arbitrary means out of an Observer's rest frame. In being accelerated it radiates energy. This is more easily grasped if, after we accelerate the electron for a while, we decelerate it back into the Observer's rest frame as shown in Figure 1. The acceleration and deceleration speeds are assumed constant and equal in the electron's frame of reference. The velocity with respect to the Observer, and the acceleration, are show graphically.

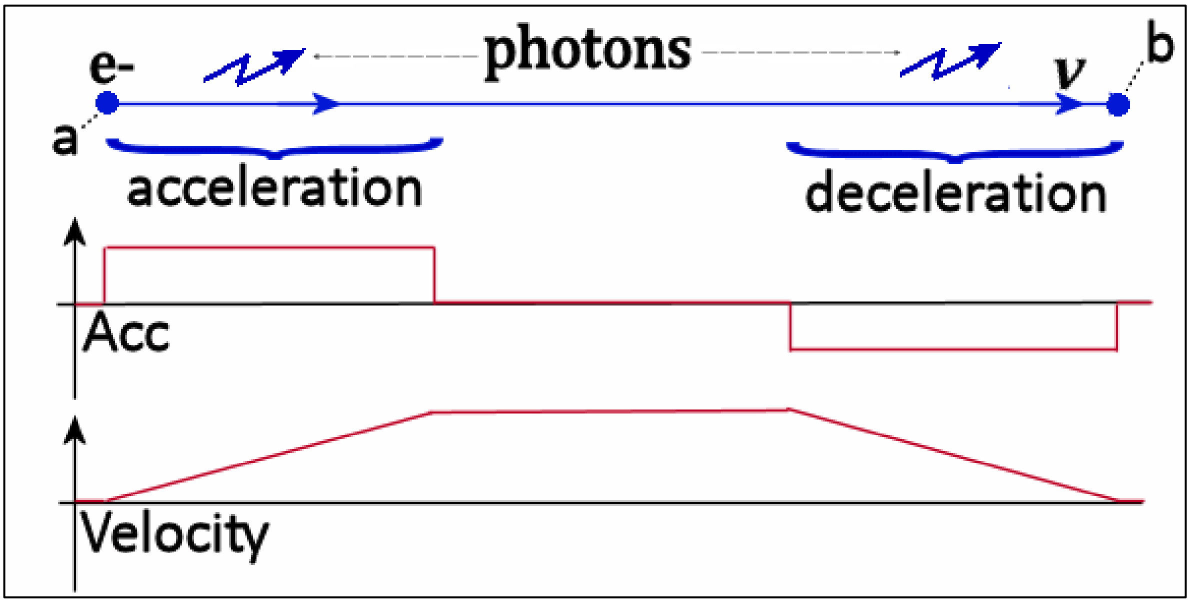

Figure 1

The electron starts from rest in the Observer's reference frame at point 'a', on the left of Figure 1. It accelerates to the right, coast for a period, and then decelerates back to rest in the Observer's rest frame on the right at point 'b'.

In the electron's rest frame it perceives acceleration, then nothing as it coasts, then an identical acceleration but in the opposite direction. The electron, in its own frame of reference, cannot perceive deceleration any differently to acceleration. Hence in both periods of electron acceleration it must behave identically, putatively emitting electromagnetic radiation. Any reactive forces arising from this radiation are mirrored, so if they were to the left (say) in the acceleration they are to the right in the deceleration.

From the symmetry in Figure 1 it is clear that whatever forces were required during acceleration must be returned in full during deceleration. Since the energy associated with these forces is $\mathrm{W} = \int \mathbf{F}\, \mathrm{d}\mathbf{L}$, where W is the work done, F is the force, and L is the acceleration distance, it follows that any energy expended in accelerating the electron to radiate this energy must be returned to the Observer's rest frame during deceleration, and there is therefore no net expenditure of energy to provide the acceleration and deceleration forces. However, two photon bursts have also been emitted so there is a net increase in the total energy of the system, by the sum of the energies in these two bursts. Hence the Principle of Conservation of Energy is violated.

It does not matter in which direction the radiation is emitted – forwards, backwards or omni-directional – so long as the same conditions apply symmetrically, as they must, to both acceleration and deceleration.

Now perhaps we can nevertheless decide that the concept of accelerative radiation is well founded, and proceed to make a device that simply bounces electrons back and forth between points 'a' and 'b' in Figure 1. At 'a' and 'b' we have perfect springs that bounce the electrons back where they come from, so the electrons oscillate back and forth indefinitely. During every transit from left to right no net energy is required to move it but it emits two photonic bursts. Equally the transit from right to left still expends no net energy but emits another two photonic bursts. We have an everlasting source of free energy!

However, as far as we know the Principle of Conservation of Energy is an absolute in our Universe. We cannot satisfy it in dealing with Accelerative Radiation. Hence the very concept must be intrinsically in error, and accelerating charges cannot emit radiation as a function of their acceleration so there is no case to answer when it comes to looking at electrons orbiting an atomic nucleus – they do not radiate because accelerating charges do not radiate.

Developing an alternative explanation

Since simple acceleration cannot cause radiation we need an alternative mechanism to explain those experiments in which it seems to appear. One such experiment is an electron accelerator. Because of the impracticality of making it in a long straight line thousands of miles long, these are created as rings, with magnets bending the path of the electrons to keep them in the ring. Figure 2 gives an idea of this. The beam of electrons is shown in plan view, travelling anti-clockwise around the ring and deflected by magnets to keep them circulating in the loop.

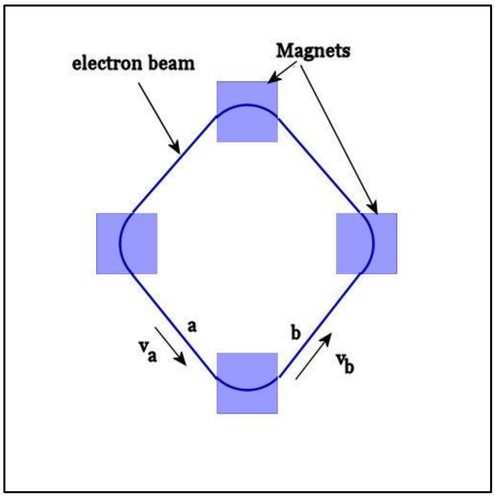

Figure 2

Let us consider only the bottom magnet with the beam of electrons passing through its field. Even if there were no issues with the Principle of Conservation of Energy there would be the problem of it working only with a special viewpoint. The theory says that the acceleration towards the centre of the loop caused by the beam bending inside the magnetic field causes the electron to lose energy so that v_b is less than v_a because of the lost radiation. However that works only from the viewpoint of an observer stationary in the rest frame of the magnets. If we move our viewpoint to that of an electron, we can see that it is stationary in its own rest frame at points 'a' and 'b' but whilst in the magnetic field it receives an acceleration that is vertically up the page towards the centre of the loop, caused by the motion-induced electric field of the magnet. The electron, knowing only of that acceleration, must somehow 'know' that we expect it to accelerate to the left (i.e. decelerate) as it passes through the bottom magnet (equivalent from our viewpoint of the electron decelerating in their left-to-right motion), presumably by ejecting radiation to the right so momentum is conserved. But how can an electron know that? It is stationary in its own rest frame apart from the acceleration and does not "know" how to eject radiation to decelerate in the magnet's rest frame. If it were travelling in the opposite direction it would have to do the reverse. There is no scenario that does not have the electron "knowing" about another rest frame.

So what is actually happening?

Let us look at point 'a' with the electron in perfect linear motion at velocity v_a. When it enters the magnetic field its motion induces a transverse electric field that causes the electron to rotate, exchanging some of its kinetic energy for rotational energy[1]. Inside the magnet the electron has rotational energy and is following a curved path. If nothing happens inside the magnet the electron will convert all its rotational energy back to kinetic energy on exit. However, having rotational energy and following a curved path inside the magnet mimics the behaviour of an electron in an atom, but the energies involved are much higher and the radius of curvature much greater than in a typical atom, so the path is equivalent to one it might take in an immeasurably massive atom, far larger than can actually exist. The rotational energy may therefore discharge into radiation just as it would in an atomic transition. Before it leaves the magnet the rotational energy has then been lost and when it starts to exit the magnet it has no rotational energy left. However, that means that in taking away the rotation that the electron gained on entry, and given that the electron has already lost that rotational energy, exiting the magnetic field causes the electron to pick up a reverse rotation. This reverse rotation takes the same energy as the original rotational energy inside the magnet even though it is reversed.

Hence the electron exchanges the rotational energy for radiant energy inside the magnet. There is no change in kinetic energy at this stage. On leaving the magnet, however, the rotational energy that would have restored the entry kinetic energy is gone, and leaving the magnetic field causes a reverse rotation which consumes more energy, reducing the kinetic energy further rather than restoring it. Hence the drop in kinetic energy is twice the energy lost from radiation in the magnet, being equal to the energy of that lost rotation, *plus* the extra energy put into the reverse rotation.

Thus the electron is now travelling past point ‘b’ with a reverse rotation and reduced velocity v_b. If nothing happens along the path between the magnets the electron will lose the rotation and regain some kinetic energy on entering the next magnet. With no rotational energy there will be no further discharge of energy whilst inside the magnetic field.

However, if the electron is accelerated while travelling past ‘b’ before it gets to the next magnet, the electron will see higher induced transverse fields and not only will the rotation it is carrying along path ‘b’ be cancelled on entry to that magnet, but a little more will be added. This extra rotation can now be incrementally discharged inside the right-hand magnet so that its rotation falls to zero before the electron leaves the magnet. Leaving that right-hand magnet will then take away even more rotation so that on exit the reverse rotation will be higher and the kinetic energy reduced.

A suitable test of this theory is observation of the emitted radiation in practice. In the classical “acceleration causes radiation” theory the greater the *absolute* electron velocity in a cyclotron then the greater the induced transverse field in the magnets and the higher the resulting radiation frequency. In this theory, the radiation frequency is a function of the *incremental* electron velocity provided to the electron on each cycle round the cyclotron, so the radiation is dependent on the *incremental* velocity and will stay more or less constant.

The electron acceleration mechanisms between the magnets do not cause radiation so it is clear that a free electron does not radiate under acceleration. However, as we have shown above, an electron bound inside a magnetic field may radiate but not as a direct result of that acceleration.

The mechanism may be the same as atomic energy-level transitions, with the electron interacting as if the transverse acceleration came from a peripheral electron shell of a hyper-massive atom.

In conclusion

The concept that electrons radiate as a result of acceleration outside the atom is poorly founded. This being the case, the lack of radiation occurring as a result of the centripetal acceleration of the electron in its orbit around the nucleus is sufficient proof that radiative acceleration is a figment. There is nothing magical about the environment which the electron experiences inside the atom that makes it behave differently to when it is outside the atom.

Reference

1. *The Free Electron's Magnetic Dipole*; Singer, Michael;1st May 2017