

Lecture 19:

Nov. 7, 2013

## Quantum Bremsstrahlung; Form Factors

Copyright©2006 by Joel A. Shapiro

Last time, we calculated that if an electron undergoes an impulse which changes its velocity from  $\vec{v}$  to  $\vec{v}'$ , in a frame where its energy doesn't change, the expected number of photons coming off with wave number in the interval  $[k, k + \Delta k]$  is

$$\frac{\alpha}{\pi} \frac{\Delta k}{k} I(\vec{v}, \vec{v}'),$$

with an angular distribution

$$\propto \frac{2\vec{p} \cdot \vec{p}'}{\hat{k} \cdot \vec{p}' \hat{k} \cdot \vec{p}} - \frac{m^2}{(\hat{k} \cdot \vec{p}')^2} - \frac{m^2}{(\hat{k} \cdot \vec{p})^2}.$$

We saw that at high electron energy,

$$I(\vec{v}, \vec{v}') \rightarrow 2 \ln \frac{-q^2}{m^2},$$

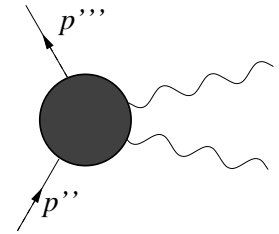
where  $q = p' - p, q^2 = -\vec{q}^2$ .

More importantly, because the energy emitted in each wavenumber interval  $\Delta k$  is independent of  $k$ , the expected number of photons diverges, both at large  $k$ , where we should not believe the results because our impulse approximation and the lack of loss of electron energy is unrealistic, but also as  $k \rightarrow 0$ , where our calculation should be correct.

Today we will calculate, to order  $e^2$ , the quantum-mechanical probability that a single photon of momentum  $\vec{k}$  will be emitted. It is clear that each additional photon emitted takes an extra power of  $e^2$ , so in perturbation theory the probability is considered small even if it is multiplied by a large constant. Thus if we find a probability greater than one, it doesn't mean a mistake in our calculation itself, but just that this order in perturbation theory will be swamped by higher order terms. We will need a better way to ask our questions perturbatively than to ask what the probability that exactly one (or exactly zero) photons are emitted.

Some more comments:

In 6.20, note that  $\mathcal{M}_0(p''', p'')$  is a matrix in spinor space.



Just below 6.36 we use

$$\gamma^0 \gamma^i = \begin{pmatrix} -\sigma^i & 0 \\ 0 & \sigma^i \end{pmatrix}$$

At the bottom of page 187 we are using

$$\bar{u} \sigma^{i0} u = -i u^\dagger \begin{pmatrix} 0 & \sigma^i \\ -\sigma^i & 0 \end{pmatrix} u \sim 0$$

$$\bar{u} \sigma^{ij} u = \epsilon_{ijk} u^\dagger \begin{pmatrix} 0 & \sigma^k \\ \sigma^k & 0 \end{pmatrix} u \sim 2m \epsilon_{ijk} \xi^\dagger \sigma^k \xi.$$

On page 188, note that if the classical Maxwell field

$$A^{\text{cl}}(x) = \int \frac{d^4 k}{(2\pi)^4} e^{-ik \cdot x} \tilde{A}(k),$$

then

$$\nabla \times \tilde{A}(k) = -i \vec{k} \times \tilde{\vec{A}}(k).$$

Read Peskin and Schroeder pp. 182–189, and also “Schwinger Trick and Feynman Parameters”, from the supplementary material posted on the web.