9.1 *energy-momentum ratio* A beam of moving particles, like an electromagnetic field, contains momentum and transports energy.

a) Find the ratio of energy current to momentum density for a beam of particles with mass m and speed v. (The number of particles doesn't matter because it cancels out. Don't assume $v \ll c$.) Compare this ratio to the ratio of energy current to momentum density for electromagnetic fields, as discussed in Griffiths, Chapter 7.5.

9.2 *Tangential-E reflection/transmission (cf. Griffiths 8.16)* An electromagnetic wave is incident at angle θ_I to the normal of a surface. The polarization is normal to the plane of incidence, so that E points along the surface. (The case treated in class had E in the plane of incidence.)

a) Find the reflected E amplitude E_{0R} in terms of the incident amplitude E_{0I} using the quantities α and β defined in Griffiths. Find the transmitted wave amplitude E_{0T} in terms of E_{0I}. Compare to Griffiths 8.117.

b) If the incident wave is normal to the plane, this polarization is indistinguishable from the case calculated in Griffiths. Show that the amplitudes calculated in a) reduce to those previously calculated.

c) Find the sum of transmitted and reflected intensities relative to the incident intensity.

9.3 *Magnetic phase-lag in conductor (Griffiths 8.20)* An electromagnetic field is normally incident on a conductor with high conductivity σ. The fields in the conductor oscillate and decay with distance from the surface. There is also a difference in phase between the electric and magnetic field: B crosses zero a fraction of a cycle before or after E crosses zero.

a) What fraction of a cycle is this?

b) What is the ratio between the B amplitude and the E amplitude?

9.4 *Energy and momentum at a conducting surface* Radiation of angular frequency ω hits a surface with conductivity σ and dielectric constant ϵ and $\mu = \mu_0$ at normal incidence. This is a good conductor, for which $\sigma \gg \omega\epsilon$.

a) What fraction of the transmitted energy is dissipated within one skin depth?

b) The transmission coefficient T and the electric fraction of the energy density u_E/u_B both go to zero in the good-conductor limit. Find a formula giving T in terms of u_E/u_B in this limit.

c) If a 5 mw laser shines at normal incidence on the surface, what force does it exert? (You could do this using the notion of photon momentum or the classical notion of momentum current. You should be able to do it both ways.)