# PHYS 2020: College Physics
## Manic Monday #3

*"Magnetism, as you recall from physics class, is a powerful force that causes certain items to be attracted to refrigerators."* ∼ Dave Barry

## Solar Coronal Loops (and Magnetism!)

Over many years of solar observation, we have discovered a connection between sunspots[1] and regions of intense magnetic activity on the surface of the Sun. Sunspots appear dark in ordinary visible light, but are blindingly energetic in the x-ray spectrum. The image below was taken by the TRACE satellite, which shows million degree plasma arching over the surface of the Sun in a *coronal loop*. This kind of fine filamentary structure should look tantalizing similar to magnetic fields that you've been learning about.

In this problem, we will examine the role that magnetism plays in the dynamics of the gas in a loop like that shown above. These types of computations are important in predictions of solar weather – they help us understand solar flares, eruptions, and storms that send energetic particles toward Earth where they can disrupt power systems, satellite communications, cell phone networks, and cause spectacular displays of the *aurora borealis*. The Sun goes through an 11 year cycle of activity between periods of high magnetic activity. It has been suggested that this cycle can have important consequences for climate on Earth and the other planets[2].

**A**▷ At the surface of a sunspot, assume the magnetic field emerges perpendicular to the Sun. The eruption that gives birth to a solar flare spews solar plasma (charged, hot gas) out at a speed of 275 km/s, at an angle of 65° to the surface of the sunspot. Draw a free body diagram showing all the forces acting on a small blob of the plasma. Assume the plasma has a *positive* charge.

**B**▷ Suppose the blob of plasma has a mass of $10^{-6}$ kg and carries a net positive charge of $10^{-7}$ C. If the gyroradius of the blob in the magnetic field is $5.8 \times 10^3$ km (about the radius of the Earth), what is the strength of the B-field emerging from the sunspot?

[1] Dark areas on the photosphere of the Sun. They have temperatures of roughly 4000 K, but appear dim next to the surrounding surface of the Sun at 5800 K!

[2] A piece of evidence relating to this is the fact that a long period of inactivity known as the *Maunder Minimum* corresponds precisely with a cold period in Europe known as the "Little Ice Age" in the late 1600s.

**C**▷ What is the *total acceleration* $\vec{a}$ that the plasma blob experiences? Express your result in terms of a component that points vertically with respect to the sunspot, and a component that points parallel to the surface.

**D**▷ Make a sketch showing the trajectory the particle will make as it flows upward.

**E**▷ To what maximum height will the plasma reach when it is ejected from the surface of the Sun[3]? It may be helpful to remember the general definition of the acceleration due to gravity: $g = GM/R^2$.

**F**▷ How long will it take the plasma to reach its maximum height?

**G**▷ What average electrical current does this flow of plasma up and down the coronal loop represent? Is this a large current?

**H**▷ A typical coronal loop may be filled with $10^{13}$ kg of material. If it is all made up of blobs like that in part (B), how much electrical charge is contained in the loop? Is this a large amount of charge[4]?

[3]What? You mean I have to remember some kinematics? D'oh!

[4]When coronal loops break open, all this material spills out in a *solar flare* or *coronal mass ejection*, and all this charge flows towards Earth. This is why solar storms can be so devastating.