MAGIC

2012-07-20

As promised last time, this update will contain a bit of physics. As we all know, physics is fun (or "phun," as one friend informed me). Physics explains how the world works and attempts to find underlying principles that connect and explain various phenomena, allowing predictions about the behavior of new systems. I will provide one example of how physics unifies various phenomena in this update. I'll try to keep it as simple as I can, but if the details prove to be too much, I hope everyone still gets the essential ideas.

Of all the tools we have in our arsenal to measure properties of clouds, aerosol particles, and the atmosphere, radars are among the most powerful. The word "radar" stands for RAdio Detection and Ranging, and radars use radio waves to detect objects and determine their distances. Radio waves are emitted by an antenna and the pulses that reflect off objects such as aircraft, birds, raindrops, or cloud drops are detected. The size of the object is determined by how strong the reflection is and the distance to the object, which in turn is determined from knowledge of two quantities: 1) the time between when a pulse was emitted and when its reflection off the object was detected, and 2) the speed the radio wave travels, which is the same as the speed of light.

Radio waves travel at the speed of light because radio waves and light are essentially different forms of the same phenomenon—this is the unification to which I referred above. This phenomenon is called electromagnetic radiation (this is different from the radiation that refers to radioactivity). Microwaves, x-rays, gamma rays, and infrared and ultraviolet light are also forms of electromagnetic radiation. Each of these forms consists of an electric field and a magnetic field that oscillate in perpendicular directions while propagating (i.e., moving) at the speed of light. If you were standing in one place and electromagnetic radiation passed by you, there would be an electric field that moves up and down and a magnetic field that moves back and forth. These oscillations occur at the same speed, and the entire wave moves forward at the speed of light. A rough analogy is a water wave at the coast; water at one place moves up and down as the wave itself moves forward.

The property that distinguishes different forms of electromagnetic radiation from each other is the time it takes for the electric field to make one complete oscillation up and down (or equivalently, the time it takes for the magnetic field to make one complete oscillation back and forth); this time is called the period of the wave. Another way to describe this property is by the frequency of the wave, which is the reciprocal of the period; the frequency is how many times per second the oscillations occur. Yet another equivalent description is the distance the wave travels before the electric field (or magnetic field) makes one complete oscillation; this is defined to be the wavelength. The frequency and the wavelength are related by a simple equation that contains the speed of light.

The energy carried by an electromagnetic wave is related to its frequency: the higher the frequency, the greater the energy. Gamma rays have the most energy, followed by x-rays and then ultraviolet light, which has more energy and a higher frequency than visible light (hence the name "ultra," meaning beyond). Being in the sun for a long time can lead to sunburn and skin cancer because the ultraviolet radiation has enough energy to break chemical bonds in our cells. Infrared light has lower energy then visible light (hence the name "infra," meaning below); microwaves have lower energy still, and radio waves have even less energy than microwaves.

Electromagnetic radiation is ubiquitous in our daily lives. We get up in the morning and open our eyes and see (visible light). We wake up to the radio (radio waves) and turn on the television (also radio waves). When we tune the radio to a different station, or change a channel on TV (using a remote, which sends infrared radiation), we change a dial or a setting that changes properties of an electric circuit so that electromagnetic radiation of a different frequency is detected. The numbers on the radio are the frequencies of the radio waves. FM and AM are in different frequency ranges, and these terms refer to how the electromagnetic radiation is modulated, or modified, to allow it to carry information. In FM, or frequency modulation, the frequency of the radio wave is varied by small amounts, and this variation is used to carry information such as the music we hear. In AM, or amplitude modulation, the strength of the radio wave is varied slightly, and this variation carries the necessary information. As mentioned above, TV signals are also radio waves, although the channel numbers aren't equal to the frequencies. Other common devices that send information using radio waves are Bluetooth, wireless keyboards and mice for the computer, and cell phones.

Different frequencies of visible light are interpreted by our eyes as different colors. These different wavelengths interact differently with physical objects, which is why different objects appear as different colors. Similarly, different frequencies of electromagnetic radiation interact differently with the air, which is why we see the sky as blue, and with water drops, which is why we see rainbows and why microwave ovens work (physics is not only phun, it explains the world!). To “interact differently” means that the way electromagnetic radiation is reflected, scattered, absorbed, or refracted (i.e., the direction of the wave is changed, such as when a pencil that is partly in a glass of water appears bent) depends on the frequency. Thus, water drops of a given size will interact different with radio waves of different frequencies. Conversely, the way electromagnetic radiation of a given frequency interacts with an object depends on the properties of the substance comprising the object and on its size and shape. Thus, water drops of different sizes will behave differently in a given radar beam, an effect we exploit to infer sizes of cloud drops and raindrops.

The take-home message from this update is that radio waves, microwaves, infrared light, visible light, ultraviolet light, x-rays, and gamma rays are different manifestations of the same phenomenon and differ from each other only in their frequencies (or equivalently, their wavelengths). In a sense all of these waves are merely different colors of light, some of which are outside the range of frequencies that our eyes can detect.

I’m headed off to Argonne National Laboratory in a few days to see the containers with all the instruments that are being set up and readied to be sent to Los Angeles, where they will be loaded on the ship in August (things are coming together for MAGIC!). In the next update I’ll give a progress report on MAGIC, and I’ll discuss different types of radars.

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Please address any questions or comments to elewis@bnl.gov.
All updates and other MAGIC information can be found at http://www.ecd.bnl.gov/MAGIC.html.