Teacher Tune-up

Quick Content Refresher for Busy Professionals

How can energy travel when matter doesn't?

Energy sometimes travels with matter, but it certainly doesn't have to.

When an object is set in motion, it acquires kinetic energy (KE). If the object hits another object, it can do work on that other object. A flying bullet or a falling rock have kinetic energy, and impart that energy to other matter when their motion is opposed. Water flowing downhill has kinetic energy and can do work on the turbine in a power plant.

But energy can also be transmitted from point A to point B without any material object making the whole trip. Energy travels without material luggage by means of waves. There are many kinds of waves, but all of them share this characteristic: *waves transfer energy from one place to another without transferring matter.*

Mechanical waves transmit energy over long distances through physical media (gas, liquid, or solid) without the location of the matter in the medium being permanently changed by the waves. For example, in compression waves (like sound), particles in the medium tend to transfer energy to their neighbors by a pushing force parallel to the direction the wave is moving. Since the particulate motion is *along* the direction of the waves' motion, this kind of wave is called *longitudinal.* Particles in the medium of a longitudinal wave return to their original position after moving only slightly. The air molecules that transmit a sound typically move only a fraction of a millimeter except close to a loudspeaker. (That's why you can sing or shout at a candle at close range without blowing it out: sound is a vibration, not a wind.)

In transverse mechanical waves (like waves on the surface of water, or in a snapped rope), particles tend to transfer energy by exerting a pulling force transverse to (i.e. perpendicular to) the direction the wave is moving. An ocean wave can travel thousands of miles even though each of the many individual water molecules involved mostly move only a few feet.

Energy needs no material medium at all when it travels by means of electromagnetic radiation—visible light, infrared, x-ray etc. Unlike sound, earthquake shocks, or waves on the surface of water, electromagnetic waves can travel through a vacuum. Indeed, they travel fastest through a vacuum. Although many kinds of matter will allow certain frequencies of electromagnetic radiation to pass through (a phenomenon we call transparency), matter tends to slow down EM radiation. The different speeds at which light travels through different media is at the root of the bending of light that makes a straight stick look broken where it enters the water, and that separates different wavelengths of visible light into rainbows.

You could say that electromagnetic radiation is a kind of vibration of space itself, rather than of matter. More specifically, the reason visible light and other electromagnetic waves can pass through a vacuum is that they depend on the propagation of *fields:* electrical fields and magnetic fields. Just like gravitational fields, these fields act without direct material contact. They transmit force and energy by altering space.

Every beam of light begins with vibrating electrons. Charged particles like electrons have electrical fields, and the acceleration of charged particles alters their electrical field and induces a magnetic field. Changing magnetic fields, in turn, induce changes in electrical fields. When electrons oscillate back and forth (in a human-made transmission antenna, for example, or in a star where the storm of energy keeps electrons jumping and falling back and forth between different orbitals within atoms), the moving charges generate oscillating electrical and magnetic fields. These fields perpetuate each other and propagate at the speed of... well, light, because this propagating electromagnetic field oscillation is just what light is.

These electrical and magnetic fields keep inducing each other and dying away, leapfrogging through space in transverse waves until and unless they encounter matter. When EM waves do hit matter, the way they interact with the electrons in atoms determines whether they are reflected, absorbed, bent, or passed on through the matter.

But in any case, the transfer of energy by electromagnetic radiation has no more need of a material medium than does the pull of gravity.