Teacher Tune-up

Quick Content Refresher for Busy Professionals

Why do electromagnetic signals (and lots of other phenomena) get weaker with distance?

Signals broadcast as AM or FM electromagnetic waves grow weaker with distance. Similarly, electromagnetic radiation in the visible spectrum—i.e. visible light—loses intensity with distance. Indeed, a variety of phenomena share this dilution of effect over distance. A ringing bell sounds louder when you're right next to it than it does when you're a mile away. The gravitational pull of a star is stronger when you're close to it, weaker when you're far from it. The farther apart static electric charges are, the weaker their interaction becomes.

It's easy to see that the intensity of these phenomena is *inversely related to distance*: more distance means less intensity. But it may be less intuitively obvious that intensity always varies with the inverse *square* of the distance. There is a widely applicable Inverse Square Law, which states that the intensity of such phenomena is inversely proportional to the square of the distance from their source.

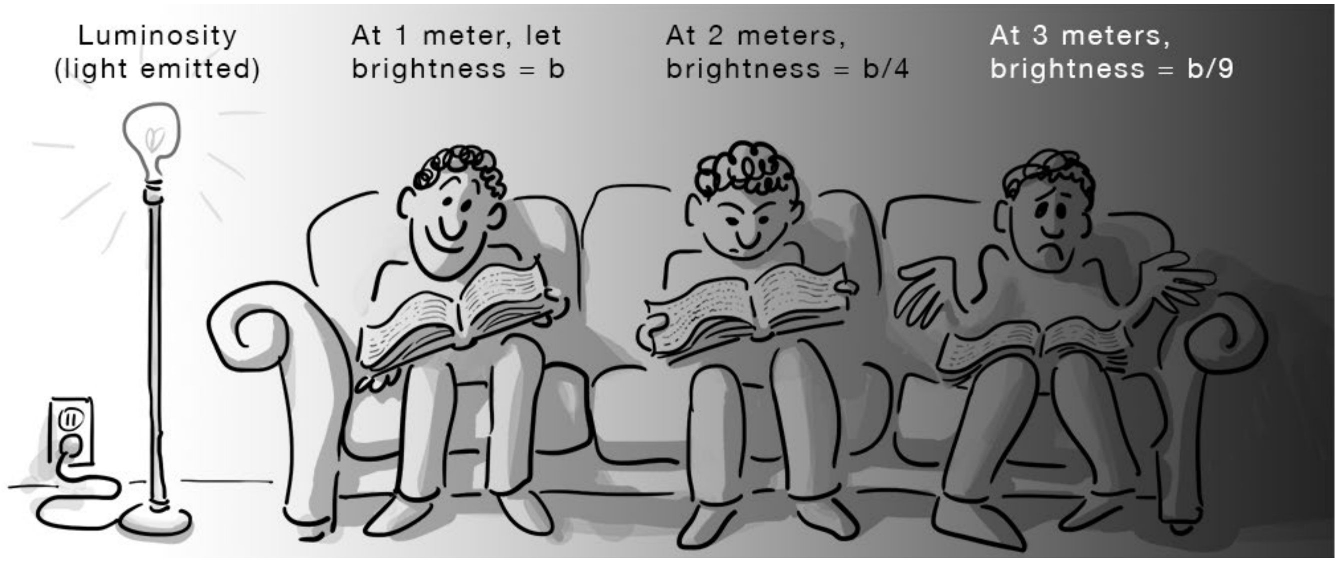
$$\text{intensity} \propto \frac{1}{\text{distance}^2}$$

(The symbol $\propto$ above is an alpha, and here it means "is proportional to"; it's kind of like an equals sign, but when we use this proportionality symbol, we can be more relaxed about technicalities like units and constants.)

For example, the intensity of light diminishes with the square of the distance from the light source. We should distinguish between the intensity of light *emitted* at the source, called **luminosity**, and the intensity of light *received* at various distances, called **brightness**. Clearly, both emitted and received light intensity can vary: one light bulb may be twice as luminous as another; and the light from a certain bulb gives greater brightness to the pages of a nearby book than to the pages of a far away book.

The Inverse Square Law, as applied to light, tells us that received brightness varies with the inverse square of distance from a luminous source.

$$\text{brightness} \propto \frac{\text{luminosity}}{d^2}$$



What are some other applications of the Inverse Square Law?

Moving on from radio signals and light, we find the Inverse Square Law popping up in the behavior of gravity and of charged particles. Newton's Universal Law of Gravity says that the force of gravitational attraction between two bodies is proportional to the product of their masses divided by the square of the distance between them:

$$F_{gravity} \propto \frac{m_1 m_2}{d^2}$$

And according to Coulomb's law, the electrostatic force of attraction between opposite charges (or of repulsion between like charges) is proportional to the product of the charges divided by the square of the distance between them:

$$F_{charge} \propto \frac{q_1 q_2}{d^2}$$

Again, it makes intuitive sense that *d*, distance, is in the denominator of the fractions above, because in general, the farther away something is, the less effect it has. But why is the distance *squared* in all these cases?

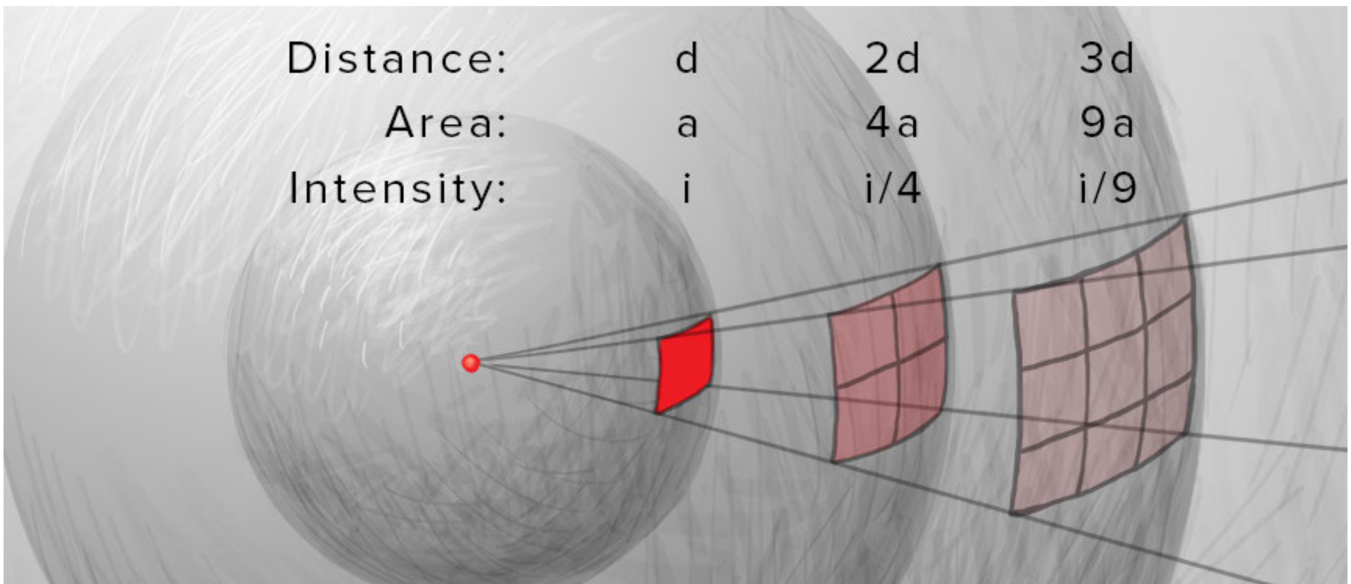
How does geometry explain the Inverse Square Law?

Some simple geometry underlies these different instances of the law, and because this effect applies to all these phenomena and more, you can get a lot of intellectual bang for your buck by understanding what's going on here.

The sound of a ringing bell, the broadcast signal from a radio station, the light and also the gravitational influence of the sun, and the electrostatic influence of an electron or a proton all spread out evenly from a central source, losing intensity with distance. Well, if distance from a center is important, we may gain some insight by thinking about the geometry of a sphere (which is the set of all points equidistant from a central point).

The formula for the surface area of a sphere is $4\pi r^2$. Note that the 4π is constant, and that what determines the surface area of a particular sphere is the *square of the radius*. Now imagine an expanding sphere. In fact, let's make this image more concrete by picturing a bubblegum bubble being blown larger and larger. This is an unusually well behaved bubble: it maintains a nice spherical shape, and the gummy skin of the bubble stretches in such an ideal way that it has a uniform thickness all around. But there is only a certain amount of gum, so as the bubble expands, the skin must grow thinner. The thickness of the gum is inversely related to the area over which it is stretched (more area = less thickness). More specifically, because the surface area of the bubble grows with the *square* of its radius, the skin of the bubble must stretch thinner in proportion to the *inverse square* of the radius. Whenever the bubble doubles in radius, the skin stretches to one quarter of its former thickness.

The total volume of the gum is analogous to the total fixed quantity of anything that spreads out evenly from a central point, such as the energy in a burst of light. Like the skin of a bubble, the intensities of light, sound, gravity, and electrostatic force are stretched thin, attenuated, diluted with the square of the distance from their source. All these phenomena, acting through space, must obey the same rules of geometry.



Geometry of the Inverse Square Law
The generalized "intensity" here could be brightness of light, or strength of gravitational attraction, etc.

See also: [What is gravity?]