Fun with the setting sun

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The setting sun plays a few tricks that any physicist will appreciate. One of these is well known: the sun appears unusually red when setting. It is the $1/\lambda^4$ dependence of Rayleigh scattering which selectively removes the blue end of the spectrum from the transmitted light.

Less well-known is the fact that the sun is not where it seems to be, during sunset. In fact, it may be behind the horizon while we still see it. We are not talking here about the finite speed of light, which makes us see the sun about 8 minutes late. We are talking about the refraction of the sunlight due to the vertical gradient in the index of refraction, which in turn is caused by the density gradient. If we ignore temperature gradients for a second, the density decreases with height due to the decreasing atmospheric pressure, by a little over 1% for every 100 meter, *i.e.*, $n^{-1}(dn/dz) \approx 1x10^{-4}$. As a result, the light rays are bent downward, in the direction of the earth's curvature. This may be seen as the inverse of the well-known 'highway mirage', the apparent pools lying across the pavement when the sun shines.

Granted: temperature effects can be larger than the barometric pressure effects, which is easily seen if we realize that, for constant pressure, we have $n^{-1}(dn/dz) = -T^{-1}(dT/dz)$. But let us look at what happens if temperature gradients are negligible, or – even nicer – if temperature increases with altitude. Then the temperature effect – if any - adds to the barometric pressure effect. Now the light rays tend to follow the earth's curvature, which makes us see the sun just after sunset. This effect occurs both at sunrise and at sunset, and adds an extra 5 minutes of daylight to each day. Note that the finite-speed effect mentioned above does not do that; it just gives an 8-minute offset throughout the day.

Since bending of light rays in the atmosphere is stronger for lower-lying rays, there is a second phenomenon: the sun appears to be flattened by about 10%. The fact that we do not always notice this is due to the competing effect of temperature.

Finally, there is the somewhat mysterious 'green flash' that people sometimes observe at the moment of sunset. It lasts only for a few seconds, and requires somewhat favourable atmospheric conditions. Why green, and why only for a few seconds? There are a few things here that we have to combine. First the refraction, which makes us see sunlight after the actual sunset. Due to dispersion this effect is strongest for the blue end of the visible spectrum. This means that we expect blue to be visible longest, while the red end of the spectrum has long disappeared. But blue light is almost absent in the setting sun, as seen above. The result is that the last flash of sunlight is dominated by green.

The green flash: a last good-bye from the setting sun. But at least a good-bye in style. ■