Comments on Fundamental Physical Constants

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Fundamental physical constants are a key part of modern physics. Here I explain how fundamental constants can be thought of as c*onversion constants* which convert one set of units to another.

For example the **Boltzmann constant**, k_B, converts Kelvins to Joules. The Boltzmann constant is considered more "fundamental" than the conversion factor between inches and meters because it was a fundamental discovery that Kelvins and Joules actually measured the same quantity (whereas there was never any doubt that inches and meters both measure length). People measured and discussed temperatures long before they realized that temperature is just a measure of energy. (It measures the energy in a typical degree of freedom of a large thermalized system.)

Likewise, **Planck's constant**, $\hbar$, converts (meters)$^{-1}$ to units of momentum. People measured and discussed momentum long before quantum mechanics taught us to think of momentum in terms of the d/dx operator, which has units of inverse length. (A similar comment applies to conversions between energy and frequency.)

Also, special relativity has taught us how space and time "rotate" into one another when one changes reference frames. The **speed of light**, *c*, can be thought of as conversion constant which converts units of time into units of space.

Newton's constant, *G*, is also interesting: According to Newton's original theory it allowed us to convert a combination of masses and distances into a force. Einstein's theory taught us that G/c^2 converts mass into length… related to the radius of curvature of spacetime.

One's choice of units is always a matter of convenience. An astronomer measuring clusters of galaxies would much rather use Megaparsecs than inches. One's choice of units usually says a lot about the system one is looking at. Each of the fundamental constants mentioned above is related to an important property of the physical world around us:

The existence of k_B reflects the fact that it is usually convenient for us to measure thermal and macroscopic energies in different units. It just so happens that we live in a world where these two types of energies typically have very different values.

Similarly, c reflects the fact that most matter around us is non-relativistic, and $\hbar$ exists because the inverse length scales corresponding to macroscopic momenta are very much smaller than the macroscopic length scales we are used to dealing with. The fact that everyday masses curve spacetime on lengths very different from lengths we measure directly leads to the conversion constant G/c^2.

It is no accident that the fundamental constants are all very different from unity in everyday units. If typical thermal energies were the same as macroscopic energies, “temperature” and “energy” would never have developed as separate notions. Similarly for G/c^2, $\hbar$ and c. So really, what is “fundamental” about fundamental constants is that they reflect truths about the universe which were hidden due to features that the world around us happens to have. Once scientists dug deeper and uncovered these truths, a conversion factor (or fundamental constant) was needed to reconcile the fact that two apparently different quantities turned out to measure the same thing.

Adapted from http://albrecht.ucdavis.edu/download_file/view/71/236