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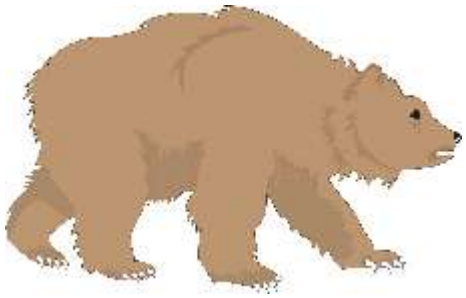
Ursus Philosophicus

Essays dedicated to Björn Haglund on his sixtieth birthday



The Ontology of Temperature

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Abstract

It is argued that temperature is a mind-independent emergent quality that supervenes on the kinetic energy of molecules and vibrating atoms. That is, temperature cannot be reduced to sensations of temperature, to a social-conceptual construction, or to kinetic energy.

To Björn Haglund,
who once wrote a book about Wilfrid Sellars,
who once wrote a paper defending the possibility of emergent qualities.

1. The ontological status of temperature

In everyday life, we take it for granted that we can perceive as well as measure mind-independently existing air temperatures and body temperatures. In the history of science, the creators of classical thermodynamics thought that objective temperature could be scientifically studied and that natural laws involving it could be found. In contemporary philosophy, even though temperature is hardly ever discussed, the dominant implicit views seem to be that temperature is only a purely subjective sensation, only a social-conceptual construction, or identical with kinetic energy. I will argue that all these views are false, and that temperature is a mind-independent emergent quality (also to be called "emergent quantity dimension") that supervenes on the kinetic energy of molecules and vibrating atoms.

2. Temperature *versus* subjective sensations of temperature

There is no one-to-one correspondence between our sensations of temperature and the temperature shown by a thermometer. We are bad thermometers. Does this fact show that there is no mind-independent temperature? No, this non-correspondence can easily be given another explanation. Subjective experiences of air temperature are determined by at least four different factors, objective temperature being only one of them. Apart from the temperature itself, our sensations of air temperatures depend on the wind, on the humidity of the air, and on our general state of health. Since this explanation has as one its explaining factors objective temperature, it cannot possibly imply that there is no such temperature.

3. Temperature *versus* temperature scales

Not only concrete thermometers, but also the abstract temperature scales they are made to express are human constructions. Doesn't this fact imply that temperature itself must be a human construction, too? No, it does not. Let us take a quick look at scales. There are some lines of thought that – falsely – may be taken to imply that what is measured by a scale is as much a human construction as the scale itself.

First, and trivially, the fact that pictures, concepts, and statements are human inventions does not imply that they cannot picture, denote, and describe entities that exist independently of themselves. Rather, this very capability is the reason why they have been invented. And the same is true of scales.

Second, like all metrical scales, every temperature scale has a conventional standard unit. For instance, we can translate degrees Fahrenheit into degrees Celsius and vice versa: $^{o}F = 1.8\,^{o}C + 32$; and the same goes for degrees Kelvin, which is used in physics. But this kind of conventionality is no more mysterious than the conventionality of language signs. The fact that "cat" means the same as the Swedish "katt" does not imply that these words cannot denote anything, and the fact that "$32\,^{o}F$" means the same as "$0\,^{o}C$" does not imply that these magnitudes cannot be measures of a mind-independently existing temperature.

Third, every temperature scale contains a linear ordering. Isn't at least this ordering necessarily wholly man-made? No, it can be an ordering that is just as

grounded in nature as the ordering of the length scale is. Anyone who accepts that there are mind-independent qualities, ought to accept that spatial extension is such a quality. Look now at the spatial extensions of the following four lines and the resemblance relations between them: A –, B —, C ——, D ———. The facts that A resembles B more than C in length, that B resembles C more than D in length, and that A resembles C more than D in length are something that we *discover*. We cannot by a mere act of will impose this ordered structure on these four lines. The resemblance relations in question are grounded in the nature of the four length instances. If there is objective temperature, then it can in the same way contain an objective ordering.

Every statement such as "The air in this room has a temperature of 19 °C" makes explicit use both of a concept for a quantity dimension, "temperature", and a concept for a determinate quantity, "19 °C", but implicitly it also connotes all the other determinate quantities of the scale. Also, of course, it is surrounded by epistemological problems. Nonetheless, if true, the statement refers to an actually existing mind-independent determinate temperature. Temperature measurements can be regarded as mappings into a scale, but this view is quite consistent with the view that it is mind-independent determinate temperatures that are being measured and mapped.

4. Temperature *versus* kinetic energy

But, we have to ask next, given the assumption that from a purely philosophical point of view there may very well be mind-independent temperatures, hasn't physics shown that such temperatures can, and should, be reduced to kinetic energy? Hasn't classical thermodynamics been reduced to statistical mechanics? No, not if "reduction" is taken in its ontological sense, according to which a reduced entity has no objective existence.

In his famous discussion of scientific reductions, Ernest Nagel (1961, chapter 11) distinguishes between formal as well as non-formal conditions for reductions. Formally, it has to be required that there is a law that connects a variable for the presumed reducible quality with variables that belong to the reducing theory. Substantially, he says, it ought at least to be required that the reducing theory is able to connect some hitherto unconnected laws. Nagel uses the relation between classical

thermodynamics and statistical mechanics as his prime example, and claims that, here, both these kinds of conditions are fulfilled. Nonetheless, he says that:

> the reduction of one science to a secondary–e.g., thermodynamics to statistical mechanics, or chemistry to contemporary physical theory–does not wipe out or transform into something insubstantial or "merely apparent" the distinctions and types of behavior which the secondary discipline recognizes (1961, p. 366).

So Nagel can say, because he sharply distinguishes scientific reduction from the problem of emergence. Nagel-reduction does not imply ontological reduction. His non-formal conditions are not ontological conditions. The physicists' reduction of temperature to kinetic energy does not in itself tell us whether or not temperature is an emergent quality. And Nagel himself puts forward no definite opinion on this subject. Karl Popper, however, does; if only in passing when he discusses the mind-body problem. He says:

> According to present theory temperature is due to the movement of individual atoms; at the same time it is something on a level different from that of individual atoms in motion – a holistic or emergent level – since it is defined by the *average* velocity of *all* the atoms (Popper 1977, p. 34).

Popper claims that temperature is an emergent quality, and I will now defend this view by elaborating his remark a bit more in detail.

Disregarding some problems with idealizations such as "ideal gas", the law that connects temperature (T) with statistical mechanics and kinetic energy (E) can be written: $3/2kT = E_{ai}$. It can be rephrased as follows with respect to gases and solids, respectively:

- The temperature (T) of a gas is proportional to the *average internal* kinetic energy (E_{ai}) of its moving molecules.

- The temperature (T) of a solid is proportional to the *average internal* kinetic energy (E_{ai}) of its vibrating atoms.

Internal kinetic energy is the kinetic energy the gas or the solid in question have in a frame of reference in which they are at rest; k is merely a constant, Boltzman's constant.

The law '$3/2kT = E_{ai}$' does in itself not tell whether T and E represent a strict correlation between ontologically distinct kinds of entities, or whether T and E are inter-definable variables that correspond to one and the same feature of the world. Galilei's law for falling bodies is obviously of the former kind. In '$s = 1/2gt^2$' (where s is the distance fallen, g is a constant, and t elapsed time), no one would try to reduce distance fallen (s) to time duration of the fall (t), or vice versa. This being so, what about the law '$3/2kT = E_{ai}$'? I will rest content with discussing gas temperature. If an ontological reduction of gas temperature is impossible, then a complete reduction of temperature is impossible.

An average of a certain quantity dimension is not a quantity or a quality instance that inheres in a material entity. It is something that has a fictional or ideal kind of existence. Let me give an oversimplified example. Think of an aggregate of three molecules, m_1, m_2, and m_3. If m_1 has a kinetic energy of 2 joule, m_2 of 3 joule, and m_3 of 7 joule, then the average kinetic energy for a molecule is: $(2 + 3 + 7)/3 = 4$ joule. But there is no molecule that has the determinate energy 4 joule. The average talked about has to be a fictional or an ideal entity. Therefore, temperature cannot possibly in such cases be identified with real kinetic energy of real molecules, and to identify it with a fiction or something ideal seems ontologically absurd. However, to regard it as real, but as being correlated with an average that is grounded in real qualities of real things is quite another matter.

Next, even if it would to be the case that in each and every gas aggregate of molecules there happens to be one molecule whose kinetic energy is numerically the same as that of the average energy, it would nonetheless be impossible to identify the temperature of the gas with the kinetic energy of this molecule. One would then identify a quality of a whole aggregate with a quality of merely one part of the

aggregate. But more than this. On the assumptions given, a single molecule cannot possibly have a temperature since it cannot have *internal* kinetic energy in the relevant sense. If a molecule m has the internal kinetic energy E in a frame of reference R, then m has to be at rest in R, but a single molecule can of course not at one and the same time both be at rest and have kinetic energy.

Above, I have argued that even if temperature can be Nagel-reduced to average internal kinetic energy, it cannot possibly be identified with such a kind of energy. However, I would like to end this section by casting doubt even on the view that physics has Nagel-reduced temperature. In the International System of Units (SI) used by physicists, a distinction is made between "base quantities" and "derived quantities"; the latter are defined by means of the former, which are treated as logical primitives. There are seven base quantities (or base quantity dimensions): length (metre), mass (kilogram), time (second), electric current (ampere), thermodynamic temperature (kelvin), amount of substance (mole), and luminous intensity (candela). Kinetic energy is a derived quantity dimension defined as: mass $\cdot$ length^2 $\cdot$ time^{-2}. Intuitively, if physics really has Nagel-reduced temperature to kinetic energy, temperature ought not to be a base quantity and kinetic energy a derived quantity.

5. Temperature *versus* heat

The view defended, that temperature is a mind-independent but emergent quality that physics has not, from an ontological point of view, reduced away, does not imply that, similarly, heat has not been so reduced. In contrast to temperature, heat has become ontologically reduced, i.e., eliminated, by modern physics.

If one puts one hand on a warm piece of metal and the other on a cold piece of metal and brings the pieces in close contact, then one may perceive what happens as if there is a substance, heat, moving from the warm to the cold piece; and that this substance is responsible for the temperature changes. It is no wonder that in the history of science there are theories that postulate such a substance, sometimes called "caloric". According to contemporary science, however, there are no "heat substances", even though physicists talk both about "heat" and "heat transfer". But this is merely a way of speaking. "Heat" always means heat transfer, and "heat transfer" always means

transfer of energy (kinetic or potential). Period. There are no laws that connect anything in statistical mechanics with a heat substance. Therefore, here we find a case of ontological reduction but, interestingly enough, no Nagel-reduction.

Now a new question arises: if there is no heat substance that can move from one place to another, how can temperature changes of the kind mentioned be explained? Quality-instances themselves cannot possibly be transferred. Think of the quality of shape. If I have one spherical balloon and one egg-shaped, then the particular *instance* of sphericality of the spherical balloon cannot be transferred, even though the egg-shaped balloon may be turned spherical. Since this is a general truth about quality instances, it is true of temperature instances as well. The temperature of the warm piece cannot possibly move to the cold piece. The solution to this problem of change, however, is simple. Changes of emergent qualities need not be explained on their own level of existence. It is enough that they can be explained by means of changes on some underlying level. There is, from an emergentist point of view, nothing ontologically mysterious in the fact that temperature changes can only be explained as energy transfers in spite of the fact that temperature cannot be reduced to energy.

6. Temperature is a supervenient quality

Assuming now that temperature really is an emergent quality and quantity dimension that by means of the law '$3/2kT = E_{ai}$' is connected to the underlying levels of molecules and atoms, is there something more to be said? Yes, from a philosophical point of view there is. The view put forward implies that temperature can be characterized as a supervenient quality, too. It supervenes on aggregates of molecules and atoms that have internal kinetic energy.

Nowadays, there are several concepts of supervenience around, but I will use the original one that was made famous by R.M. Hare, and which I have explicated in detail elsewhere (Johansson 2001). According to Hare, the goodness of a person is a quality (property) that supervenes on the natural qualities of the person, i.e., on character traits, behaviour, etc. This means, says Hare, first, that it is impossible to derive a description of a person's goodness from any conjunction of descriptions of his/her natural qualities. It means, second, that two persons who are exactly alike with respect to natural

qualities are also, necessarily, equally good or bad persons. Generalizing from natural qualities to any kind of base qualities, we get the following two requirements on supervenience:

a) (The non-entailment requirement) Descriptions of base qualities do not entail descriptions of supervenient qualities.

b) (The indiscernibility requirement) If two entities have the same base qualities, then necessarily they have the same supervenient quality (base quality indiscernibility entails supervenient quality indiscernibility).

Both these requirements are fulfilled by temperature in relation to kinetic energy. (a) From no descriptions of only kinetic energy (base quality) is it possible to deduce a description of a temperature magnitude (supervenient quality). And (b) the law '$3/2kT = E_{ai}$' implies that if two things have the same average internal kinetic energy, then necessarily they have the same temperature, too.

Requirements (a) and (b) are explicitly mentioned by Hare, but I think that his writings implicitly contain two more requirements:

a)(The existential dependence requirement) Qualities that supervene cannot possibly exist without being connected to some base qualities.

b)(The multiple realisability requirement) A supervenient quality may have different base qualities.

Applied to goodness, requirement (c) says: goodness is a quality that is not able to inhere directly in a person or a thing, it is always in virtue of something that goodness comes into being. And (d) says: the same degree of goodness can be due to different natural qualities. Relying on contemporary physics, I claim that temperature fulfils these two requirements, too. Temperature is (c) a quality that is not able to inhere directly in what has temperature; it depends for its existence on qualities of the parts of the temperature bearer. If there is no internal kinetic energy (no moving molecules and no vibrating atoms) then there is no temperature at all. Even though temperature does not in itself have an absolute zero point, as the older pre-Kelvin scales bear witness of, it has because of its existential dependency on internal kinetic energy such a point indirectly. Requirement (d) is straightforwardly fulfilled: the same temperature can be

realised both by moving molecules and by vibrating atoms, and, furthermore, by different kinds of molecules and atoms.

7. The importance of temperature

Temperature is a mind-independent emergent quality that supervenes on the kinetic energy of molecules and vibrating atoms. It takes quantities and can be measured. Both air temperature and body temperature play a very important role for our well being. In medicine, objective body temperature is an indispensable health indicator. The famous ancient physician Galen (129-210) is said to have invented the first thermometer. Luck that he was not a social constructivist or a reductive materialist.

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