> *What are the quantum mechanisms behind the emission and absorption of thermal radiation at and below room temperature? If the relevant quantum state transitions are molecular (stretching, flexing and spin changes) how come the thermal spectrum is continuous? What about substances (such as noble gases) which don't form molecules, how do they emit or absorb thermal radiation?*

The thermal radiation associated with some object is typically described in terms of the "black-body" spectrum for a given temperature, given by the Planck formula (of xkcd fame (http://xkcd.com/54/)). This formula is based on an idealization of an object that absorbs all frequencies of radiation equally, but it works fairly well provided that the object whose thermal spectrum you're interested in studying doesn't have any transitions with resonant frequencies in the range of interest. As the typical energy scale of atomic and molecular transitions is somewhere around an eV, while the characteristic energy scale for "room temperature" is in the neighborhood of 1/40 eV, this generally isn't all that bad an assumption-- if you look in the vicinity of the peak of the blackbody spectrum for an object at room temperature (which is a wavelength somewhere in the neighborhood of 10 microns, way out in the infrared), you generally find that the spectrum looks very much like a black-body spectrum.

(This energy scale is the reason why most discussions of thermal radiation interacting with matter involve molecules. Molecules have some extra energy states related to their vibration and rotation, and the differences between those states are much smaller. This means that thermal radiation that won't do much of anything to an atom can drive transitions between states in a molecule, which changes the interaction dramatically. "Greenhouse gases" are common constituents of the atmosphere whose energy levels are such that they readily absorb radiation at the sort of infrared wavelengths where thermal radiation from room-temperature objects is significant. This can prevent that radiation from making it out into space, and leads to a heating of the atmosphere through directly increasing the energy of these molecules.)

How does a black-body spectrum arise from the interaction between light of whatever frequency and a gas of atoms or molecules having discrete internal states? The thing to remember is that internal states of atoms and molecules aren't the only degree of freedom available to the systems-- there's also the center-of-mass motion of the atoms themselves, or the collective motion of groups of atoms.

The central implication of the idea of thermal radiation is that if you take a gas of atoms and confine it to a "box" containing some radiation field with some characteristic temperature, the atoms and the radiation will eventually come to some equilibrium in which the kinetic energy distribution of the atoms and the frequency spectrum of the radiation will have the same characteristic temperature. (The internal state distribution of the atoms will also have the same temperature, but if you're talking about room-temperature systems, there's too little thermal energy to make much difference in the thermal state distribution, so we'll ignore that.) This will come about through interactions between the atoms and the light, and most of these interactions will be non-resonant in nature. In terms of microscopic quantum processes, you would think of these as being Raman scattering (http://en.wikipedia.org/wiki/Raman_scattering) events (not to be confused with Ramen scattering events, which happen when clumsy graduate students try to cook), where some of the photon energy goes into changing the motional state of the atom-- if you have cold atoms and hot photons, you'll get more scattering events that increase the atom's kinetic energy than ones that decrease it, so the average atomic KE will increase, and the average photon energy will decrease.

A more formal way to describe this would be to treat the atoms confined in the box as quantum systems, with the different energy states described as quantized energy levels separated by a discrete amount of energy that depends on the dimensions of the box (the bigger the box, the smaller the energy spacing, so the way to describe a "classical" situation of continuously variable energy mathematically is to set the problem up in a box, then let the size of the box become infinitely large). The temperature is then a measure of how the atoms are distributed among these levels-- as the temperature decreases, atoms are more likely to be found in low-energy states. this sort of model lets you work out the Raman processes in more detail-- the increase or decrease in energy corresponds to moving up or down the ladder of energy states.

For thermal radiation in the room temperature regime, of course, the transitions in question are so far off-resonance that a Raman scattering for any individual atom with any particular photon will be phenomenally unlikely. Atoms are plentiful, though, and photons are even cheaper, so the total number of interactions for the sample as a whole can be quite large, and can bring both the atomic gas and the thermal radiation bath to equilibrium in time.

I've never seen a full QFT treatment of the subject, but that doesn't mean much. The basic idea of the equilibration of atoms with thermal radiation comes from Einstein in 1917, and there was a really good Physics Today article (PDF) (http://www.phytem.ens-cachan.fr/telechargement/Optique_Quantique/Kleppner_Coef_Einstein.pdf) by Dan Kleppner a few years back, talking about just how much is in those papers.

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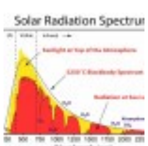

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I'm putting together slides for a TED audition talk in a couple of weeks, about how the history of quantum mechanics is like a crossword puzzle. This involves talking about black-body radiation, which is the problem that kicked off QM-- to explain the spectrum of light emitted by hot objects, Max…

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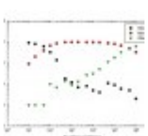

(/principles/2015/05/26/crude-monte-carlo-simulation-of-light-bulb-physics)
Last week, I did a post for Forbes on the surprisingly complicated physics of a light bulb. Incandescent light bulbs produce a spectrum that's basically blackbody radiation, but if you think about it, that's kind of amazing given that the atoms making up the filament have quantized states, and can…

Classic Edition: Not Just Air Conditioning the Laser Lab (/principles/2006/07/01/classic-edition-not-just-air-c)

I'm going to be away from the computer for the long weekend, but I don't want to have the site go completely dark, even over a weekend, so I'm going to schedule a few posts from the archives to show up while I'm away. Everyone else seems to be doing it (and pushing my posts off the front page, the…

Amazing Laser Application 2: Laser Cooling! (/principles/2010/02/10/amazing-laser-application-2-la)

What's the application? Using lasers to reduce the speed of a sample of atoms, thereby reducing their temperature to a tiny fraction of a degree above absolute zero. What problem(s) is it the solution to? 1) "How can I make this sample of atoms move slowly enough to measure their properties very...

In noble gases, what is the source/sink for infrared photons? Since it's not vibration or rotation, it must be polarization (I'm guessing).

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By Juice (not verified) on 18 Jan 2011 #permalink (https://scienceblogs.com/principles/2011/01/18/photons-and-atoms-approaching#comment-1639924)

(/user/0)

Nice post, Chad! And good point, Juice! Although, classically polarization is a process linear in field up to very high intensities. And I haven't seen a full QFT treatment of light thermalization either. It usually starts with an assumption of thermal equilibrium where all the available energy states are homogeneously filled by photons. It never says where those photons and energy states came from.

Say, we have an almost monochromatic incident field. The part of the field that is absorbed by the mono-atomic gas cloud goes into heat. When things stabilize the gas and the photons acquire a definite temperature. In fact, not all photons. Only those that were absorbed. The ones then went through or were "elastically" scattered are not "thermalized", right? Anyway, for the black-body spectrum (corresponding to the acquired temperature) to emerge the incident photons would have to be absorbed by the gas and re-emitted at frequencies (with energies) different from their initial one - inelastic scattering. This could be a multi-stage process, of course. Nevertheless, I have not seen a clear explanation about where exactly does this change in frequency come from? What's the physical mechanism? Random motion of atoms? But that accounts only for the Doppler broadening of absorption/emission lines. It cannot produce the full Plank spectrum. May be some kind of recoil? But that, I guess, would only lower the energy of emitted photons. So, there is probably no classical explanation possible. What's the official point of view, Chad?

The Raman scattering you refer to is just a fancy name for inelastic scattering. It does not explain where the continuum of available energy levels comes from in a mono-atomic gas. Are you saying that these energy levels are hidden in the (virtual) collective degrees of freedom of basically independent atoms? That's a cool idea, actually. I had never thought about it this way. Sorry for the long comment.

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