# HEAT TRANSFER NOTES

## Conduction

Conduction is the most significant means of heat transfer in a solid. On a microscopic scale, conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighboring atoms and molecules, transferring some of their energy to these neighboring atoms. This is heat transfer without (macroscopic) movement of the material. In metals especially, there is also heat transfer via the movement of free (loosely-bound) electrons. This is also what makes metals, generally, good electrical conductors.

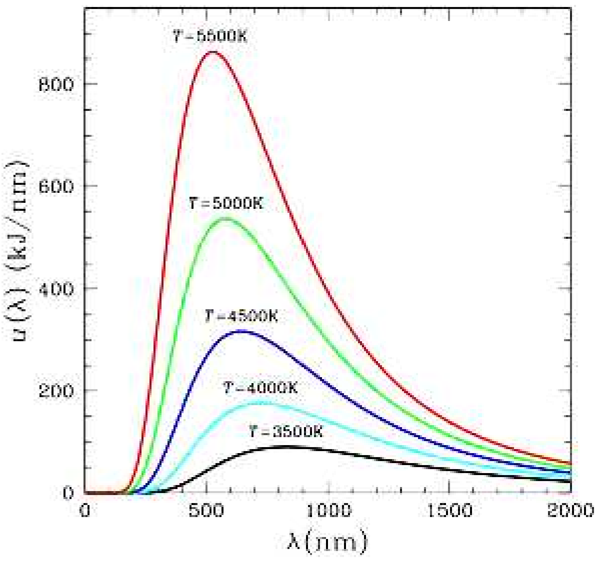
## Convection

This is a term used to characterize the combined effects of conduction and fluid flow. Two types of convection are commonly distinguished, *free convection*, in which gravity and buoyancy forces drive the fluid movement, and *forced convection*, where a fan, stirrer, or other means is used to move the fluid. Since this mechanism involves movement of the heat-transport medium, it is applicable to liquids and gases, not to solids.

## Radiation

Thermal radiation is a direct result of electron transitions in the atoms of a material. The surface of the material is constantly bombarded by radiation from the surroundings, resulting in a transfer of energy to the surface. Since *the amount of emitted radiation increases with increasing temperature*, a net transfer of energy from higher temperatures to lower temperatures results.

The frequencies of the emitted photons are described by a mathematically-complicated "distribution" that is similar in shape, roughly, to the distribution of molecular speeds (Maxwell distribution). An object at a higher temperature will emit photons having a distributional peak at a higher frequency than will a colder object. The figure below shows this distribution (of wavelengths) for several temperatures. This empirically-observed distribution was only successfully described mathematically with the advent of quantum theory.



An essential fact is that **a good absorber is a good emitter** of thermal radiation. Suppose you wanted to argue that a good absorber must be a good emitter based on the microscopic processes involving the atoms in the surface of an object. Then it becomes a question of quantum mechanics. Here is an outline of the process:

All electromagnetic radiation can be considered to be quantized, existing as photons with discrete energies that are directly related to their wavelengths (or frequencies).

But, in order for a solid to absorb a photon of *given* energy, it must have a pair of energy levels separated by *just* that amount of energy, so that the photon elevates the system from the lower member of the pair to the upper.

If a surface is an ideal absorber in visible light, this implies that there is an abundance of available electron states so that a photon of any color in the visible spectrum can interact with electrons in the solid to elevate them to an available upper level. The implication is that any color in the visible spectrum can be readily absorbed, hence it is an ideal absorber, a "perfectly black object."

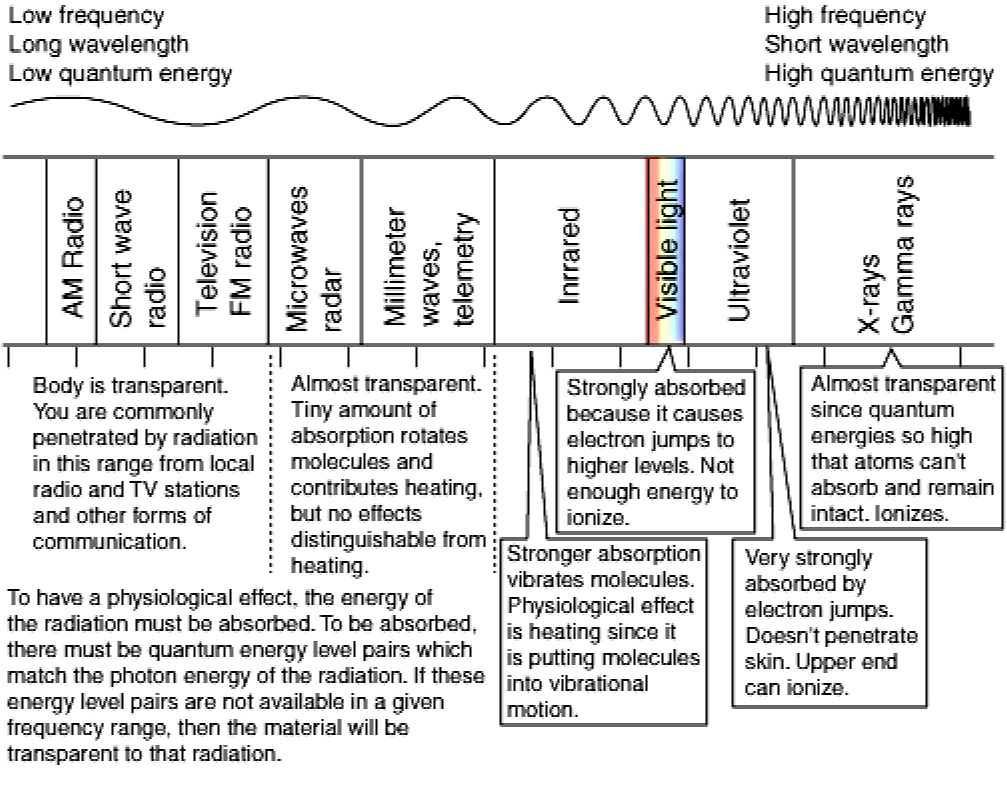
The next step is not so obvious. If a pair of electron energy levels is available for absorption of a photon, *it is also available for emission of a photon*, i.e., radiation. If it is available for an upward jump, it is available for a downward jump. One of Einstein's contributions was to show that for a given radiation, the probability for emission is the same as the probability of absorption. The implication is that this **constrains a good absorber to also be a good emitter**. If the solid has lots of available electron levels for absorption, they will also be equally available for emission.

For a perfect absorber, all visible colors are absorbed by electron jumps, but **it turns out that the elevated electrons usually follow a different path downward, cascading down in smaller jumps associated with, usually, infrared radiation**.

So we say that the light is absorbed and heats the object, associating heat with the infrared portion of the electromagnetic spectrum. The perfect absorber is also a good emitter, taking the light in as visible and re-radiating it as infrared.

Energy levels associated with molecules and atoms are in general discrete, quantized energy levels and transitions between those levels typically involve the absorption or emission of photons. Electron energy levels have been used as the example here, but quantized energy levels for molecular vibration and rotation also exist. Transitions between *vibrational* quantum states typically occur in the infrared and transitions between *rotational* quantum states are typically in the microwave region of the electromagnetic spectrum.

The energy levels for all physical processes at the atomic and molecular levels are quantized, and if there are no available quantized energy levels with spacings which match the quantum energy of the incident radiation, then the material will be transparent to that radiation, and it will pass through.



Body is transparent. You are commonly penetrated by radiation in this range from local radio and TV stations and other forms of communication.

Almost transparent. Tiny amount of absorption rotates molecules and contributes heating, but no effects distinguishable from heating.

Strongly absorbed because it causes electron jumps to higher levels. Not enough energy to ionize.

Almost transparent since quantum energies so high that atoms can't absorb and remain intact. Ionizes.

Stronger absorption vibrates molecules. Physiological effect is heating since it is putting molecules into vibrational motion.

Very strongly absorbed by electron jumps. Doesn't penetrate skin. Upper end can ionize.

To have a physiological effect, the energy of the radiation must be absorbed. To be absorbed, there must be quantum energy level pairs which match the photon energy of the radiation. If these energy level pairs are not available in a given frequency range, then the material will be transparent to that radiation.

If an atom absorbs a photon of electromagnetic radiation and remains intact, there is a strong tendency for it to return to its ground state. Just as water runs downhill, all physical systems will tend to move to lower energy levels. If the quantum energy of the radiation absorbed is higher than the average thermal energy of the molecules (that is, infrared or visible radiation), then the downward transitions may emit radiation that leaves the material, or it may be gradually transformed into general thermal energy in the material. Radiation in the microwave or longer wavelengths generally just contributes to the random molecular motion which we have described as thermal (internal) energy.