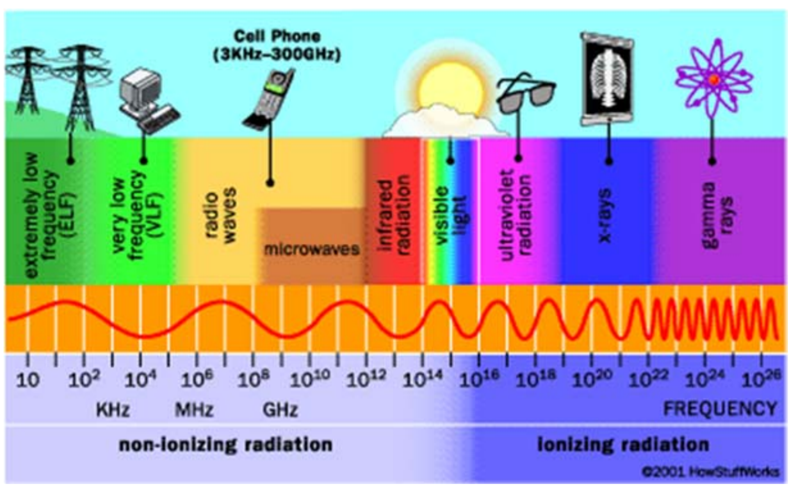
PHYS:1200 LECTURE 18 — THERMODYNAMICS (3)

This lecture presents a more detailed discussion of heat flow by radiation and its importance in the physics of the atmosphere. We will discuss some important topical issues such as the greenhouse effect and climate change.

18-1. Radiation.—Heat can be transferred from one object to another by the process of radiation. **All objects that are at a temperature above absolute zero (K) emit electromagnetic waves and by doing so they lose some heat energy**. The electromagnetic radiation emitted by one object can be absorbed by another object, thus transferring heat from one to the other.

a. Electromagnetic radiation.—We are familiar with one form of electromagnetic radiation - **light**, but electromagnetic radiation spans a very broad spectrum of waves. **Waves are characterized by either their wavelength or their frequency.** Wavelength and frequency are

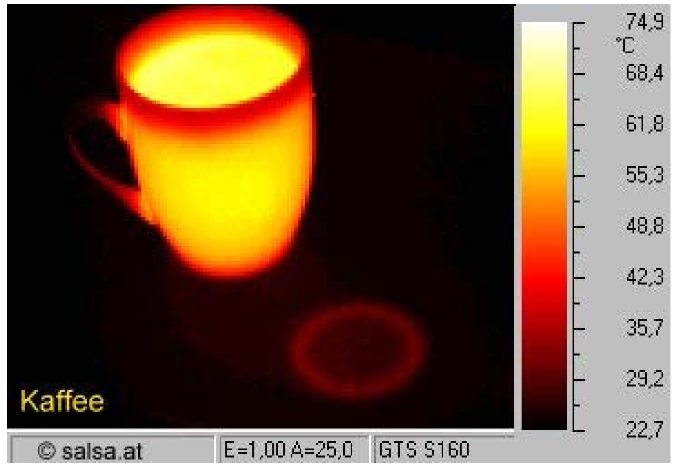


related, so it is not necessary to specify both. Visible light is just one small part of the electromagnetic spectrum; it is an important part for humans because our eyes happen to be sensitive to it.

The visible spectrum covers a wavelength range from roughly 400 nm to 700 nm (nm means nanometer or 10^{-9} m). **The wavelengths correspond to color** – short wavelengths are in the violet part of the spectrum and long wavelengths are in the red part. Wavelengths a bit longer than 700 nm are called infrared and wavelengths a little shorter than 400 nm are in the ultraviolet. The electromagnetic waves from the sun cover a large range of wavelengths, we only see the visible wavelengths. The ultraviolet emission from the sun is what causes sunburn. X-rays used to image our bones are very short wavelength electromagnetic waves.

b. Thermal radiation.—The radiation emitted by a hot object that is not in the visible part of the spectrum is called **infrared radiation**. When you turn on the heating element in an electric stove, it begins to emit thermal radiation even before it gets red hot and you can see it. You can feel the infrared radiation before the element gets hot enough to emit in the red part of the spectrum. As the temperature of an object increases, the spectrum of radiation that it emits moves toward the shorter wavelengths (**slide 8**). **The intensity of radiation emitted by an object depends on a number of factors including the area of the object, the temperature of the object and a parameter called the emissivity (slide 6)**. The emitted radiation is proportional to the temperature of the object raised to the 4^{th} power. If the temperature of an object doubles, the radiation intensity increases by 2^4 = 2x2x2x2 = 16. The emissivity factor is a parameter that measures how well an object radiated and depends on the surface conditions of the object. Poor emitters have very low emissivity values, and the best emitters have an emissivity value close to 1. This will be demonstrated in class using a device known as Leslie's cube (**slide 11**). **Dark, dull objects are generally good emitters, while shinny objects (most metals) are poor emitters**. We are told not to wear dark clothing in the summer because it is a good absorber of thermal radiation.

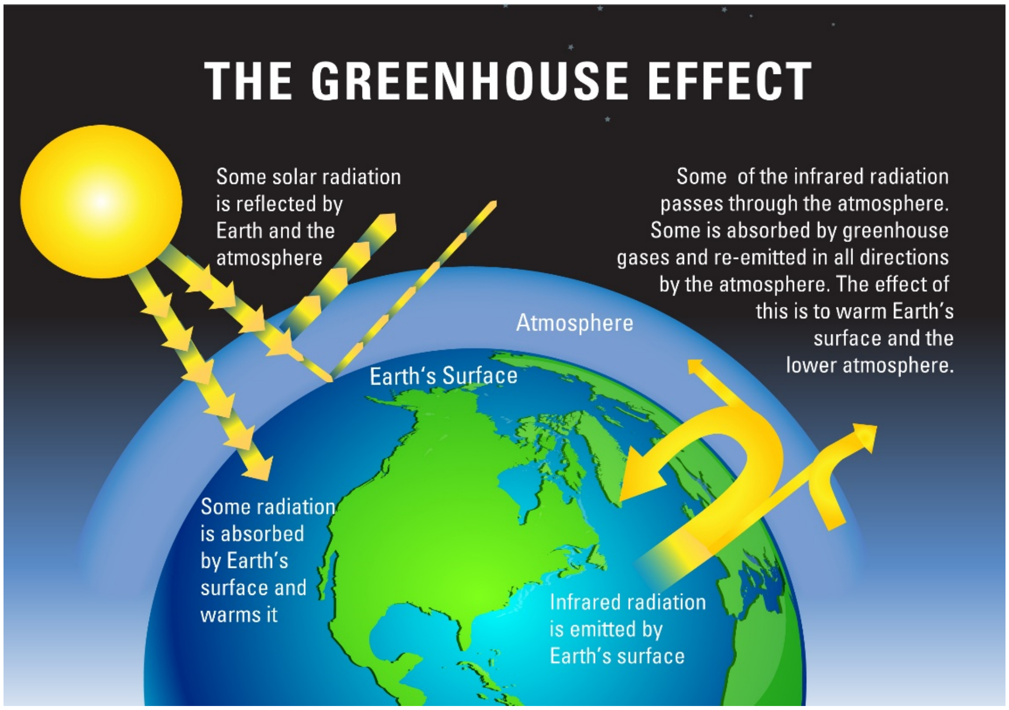
All objects not only emit but also absorb radiation. The external temperature of our body is due to a balance of the radiation we emit and the radiation we absorb. The balance between absorption and emission is what determines the temperature. Generally, objects that are good emitters of radiation are also good absorbers of radiation and vice versa. We use aluminum foil to prevent food from getting too well-done in the oven. The aluminum foil is a poor absorber and it reflects back some of the thermal radiation that would otherwise burn the food.



Although our eyes are not sensitive to thermal radiation (i.e., we cannot "see" thermal radiation), there are devices which are capable of **imaging thermal radiation**. The photo shows a thermal image of a cup of coffee. The thermal radiation is imaged and converted to a temperature, then the colors are shifted to the visible to produce a "false-color" image. If the cup of hot coffee is placed on the table, it leaves a thermal image (the red ring on the right) indicating that the temperature is higher there. The insides of a good thermos bottle have a thin coating of aluminum to reflect back some of the heat from the hot liquid in the container, thus preventing it from cooling off too quickly.

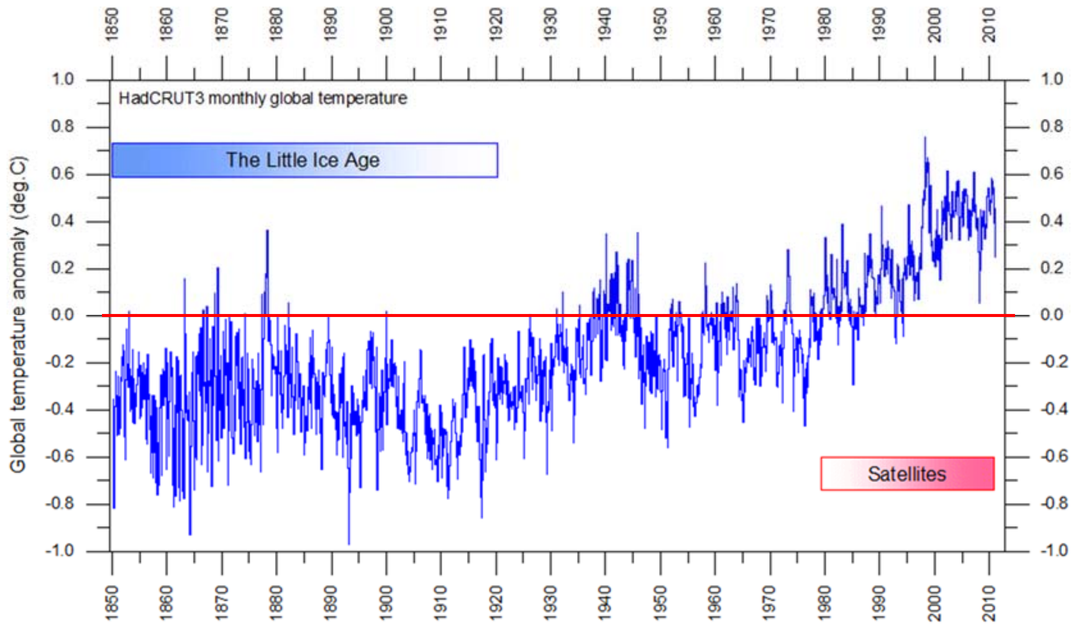
18-2. Physics of the Atmosphere.—Most of the energy reaching the earth from the sun comes in the form of electromagnetic waves**. The sun warms the earth and is the major controlling factor in our climate**. A small change is the amount of energy emitted by the sun can have a large effect on the earth's climate. Any effects in the atmosphere that cause more sunlight to be reflected can also have a big effect on climate. During the "little ice age" (roughly 1400 to 1900), the average temperature on the earth dropped by 0.5 degrees C, a significant change. This was thought to be caused by volcanic activity which injected huge quantities of particulate material into the atmosphere which blocked some of the sunlight. The earth's climate is sensitively controlled by an atmospheric process known as the greenhouse effect.

*a. The greenhouse effect.***—**This process is necessary to maintain the earth's temperature at a level where life can be sustained. Without this effect, the earth would be too cold for life as we know it – the earth's temperature would be -20 F (-29 C). The problem is that too much greenhouse effect can raise the earth's temperature. The effect is illustrated in the diagram below. When the visible light from the sun reached the earth, roughly 30% is reflected back either by the atmosphere or the earth's surface. The sun light that penetrates through the atmosphere reaches the earth's surface and heats it. The heated surface of the earth then emits invisible thermal radiation, as with any hot object. A large fraction of this infrared radiation is absorbed in the atmosphere by the so-called greenhouse gases and re-emitted in all directions. This trapped radiation then further warms the earth's surface. The primary greenhouse gases in Earth's

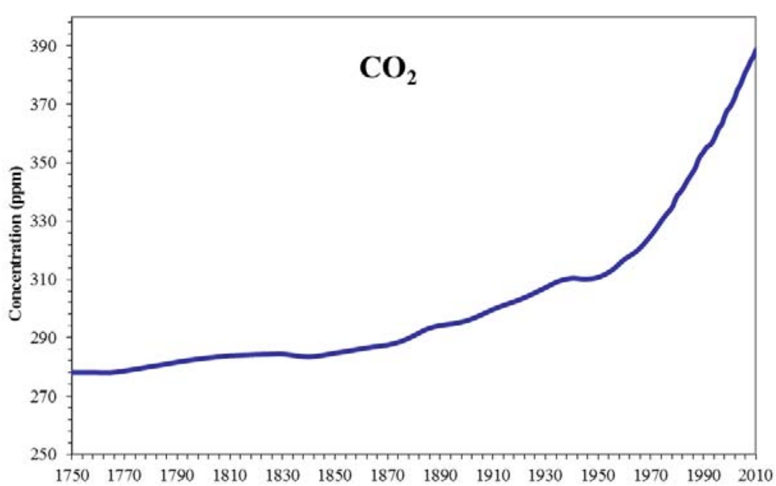


atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Actually, on a smaller scale, an effect occurs in your car when it is parked outside on a sunny day. The sun's visible light passes through the windows and heats the interior of the car which then emits infrared radiation. Infrared radiation cannot pass through glass, so it is trapped in the interior which gets warmer and warmer as the day goes on. The origin of the term "greenhouse" is for the glass rooms used to grow plants.

b. Climate change.—Some of the greenhouse gases, particularly CO_2 (carbon dioxide) are produced when fossil fuels are burned. There is evidence that the CO_2 levels in the atmosphere have been increasing in association with increased use of fossil fuels. The various factors, e.g., solar energy output, volcanic eruptions and changes in greenhouse gas concentrations, are referred to as **climate forcings** by climate scientists. The plot below shows average global temperature anomaly over a roughly 100 year period. The ***temperature anomaly*** means a departure from a reference value or long-term average. A positive *anomaly* indicates that the



observed *temperature* was warmer than the reference value, while a negative *anomaly* indicates that the observed *temperature* was cooler than the reference value. Note that there is a trend toward warming that began around 1950. The issue of greenhouse gases is that measurements show an increase in their concentrations. A plot of the carbon dioxide levels since 1750 is shown below. The increase in CO_2 levels is attributed to increased use of fossil fuels since the industrial revolution.



The controversial issues center on the question of whether or not the changes in greenhouse gases in the atmosphere are part of a natural cycle or attributable mostly to human activity (anthropogenic). Most climate scientists have come to the conclusion that the increase in greenhouse gas concentrations over the last century is due to human activity. Another hotly debated issue is to what extent these effects might be self-reversible (leave it alone and it will fix itself) or require immediate intervention to limit further increases in greenhouse gas concentrations. **Some (perhaps the majority) climate scientists argue that if no action is taken immediately, the effects will be irreversible, and lead to serious climate change effects, such as the rising of water levels due to melting of the polar ice.**

In considering these issues, **one must realize that the scientific issues may not be completely settled, and furthermore, there could be serious social, geopolitical, and economic repercussions from any actions that may or may not be taken**. Also, it may be fruitless for one country to take strong steps to decrease its greenhouse emission, since the problems are global. International consensus and binding agreements are necessary before steps are taken.

The scientific questions involve interpretations of the results of very complicated models of the atmosphere. Some climate scientists, who are skeptical, point to the fact that since 2000, there has been no further temperature increase, contrary to the predictions of many climate models. This is seen as the flattening out of the curve on the top of page 5 since 2000. This trend of no apparent warming has continued until present.