# A Most Inconvenient Reality—Greenhouse Gases Cannot Physically Explain Observed Global Warming

**Peter L. Ward**[1]

[1] U.S. Geological Survey retired.

Corresponding author: Peter L. Ward (peward@wyoming.com)

**Key Points:**

- Temperature and heat are both the result of a very broad continuum of frequencies of oscillation of all the bonds holding matter together.
- Carbon dioxide absorbs less than 16 percent of these frequencies—not constituting enough thermal energy to cause observed global warming.
- To inform sound public policy, scientists must promptly address fundamental misunderstandings about what constitutes heat and how it flows.

## Abstract

Heat is what a body of matter must absorb to warm and must emit to cool. Most scientists and engineers assume that heat is some generic thing accurately quantified by a single numeric amount of thermal energy flowing per second in units of watts per square meter. While this approximation has proven useful in many cases, it fails when comparing solar ultraviolet radiation with terrestrial infrared radiation. Planck's law, an equation formulated empirically to fit extensive laboratory measurements, shows that heat is not generic. Heat consists of a very broad continuum of frequencies of oscillation of all the bonds holding matter together. Thermal energy increases with frequency of oscillation. Each frequency has an amplitude of oscillation that increases with increasing temperature of the radiating body. Ultraviolet solar radiation is nearly 50-times more energetic than infrared terrestrial radiation no matter the amount. Amount of heat, on the other hand, is a function of the temperature difference between the emitting and absorbing bodies. Matter can only be heated by absorbing radiation from a hotter body containing higher frequencies of oscillation, with higher amplitudes of oscillation at each and every frequency of oscillation. This is why Earth cannot be heated in any way by its own radiation. Furthermore, a molecule of carbon dioxide gas does not absorb heat; it merely absorbs some spectral lines of thermal energy that are the molecule's resonant frequencies of oscillation, making up less than 16% of the broad continuum of frequencies constituting the heat required to warm Earth.

## Plain Language Summary

In 1822, Joseph Fourier first described a way of quantifying amounts of heat that is still widely used today. We have learned a lot since 1822, however, which was nearly a century before scientists could demonstrate that matter must consist of atoms and molecules.

In 1900, Max Planck developed a very different way of quantifying temperature and heat based on extensive laboratory measurements. Planck showed that temperature of matter is a function of a very broad spectrum or continuum of frequencies of oscillation of all the bonds that hold molecules of matter together. The higher the temperature of the matter, the higher the frequencies of oscillation and the higher amplitude of oscillation at each frequency. Furthermore, Planck showed that thermal energy is equal to the frequency of oscillation times a constant. This means that any amount of solar ultraviolet radiation is nearly 50 times more energetic that any amount of infrared radiation emitted by Earth. Solar radiation burns our skin, something no amount of infrared radiation from Earth can do. Solar radiation warms Earth, something no amount of infrared radiation from Earth can physically do. Bodies of matter cannot be warmed by their own radiation.

In 1859, John Tyndall showed in the laboratory that greenhouse gases absorb some infrared radiation emitted by Earth. Scientists today still assume that this means the temperature of air containing increasing quantities of greenhouse gases will get warmer and that this will increase global temperatures directly or by slowing the cooling of Earth. This fundamental assumption underlying greenhouse-warming theory has never been demonstrated in the laboratory and appears to be mistaken.

## 1. Introduction

Climate scientists have worked very hard for decades to demonstrate consensus behind greenhouse-warming theory in order to convince world leaders to make expensive and politically unpopular decisions to reduce greenhouse-gas emissions substantially and promptly before humanity faces severe consequences within the next few decades. While consensus is the stuff of politics, debate is the stuff of science. As Michael Crichton put it, "in science consensus is irrelevant. What is relevant is reproducible results. The greatest scientists in history are great precisely because they broke with the consensus."

This well-intentioned political decision by scientists to demonstrate consensus has, unfortunately, limited scientific debate about whether greenhouse-warming theory is even physically possible. It is surprising how important greenhouse-warming theory has become both politically and financially even though its veracity has never been demonstrated by an experiment in the atmosphere or in the laboratory. Experiments form a fundamental pillar of the scientific method. As Richard Feynman explains, "it doesn't matter how beautiful your theory is. It doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong." The physical sciences are all about physical reality. A physically realistic theory of global warming should be demonstrable by a physical experiment.

Greenhouse-warming theory has deep roots going back more than 200 years, although like a phoenix, it has risen from its ashes more than once because, if correct, and if the world is currently warming, it has major implications for survival of life on Earth. This would not be the first time in the history of science that such momentous possibilities might have caused some scientists to moderate their healthy scientific skepticism.

Science evolves as old ideas are constantly re-evaluated in light of new data. Carl Sagan points out how "there are many hypotheses in science which are wrong. That's perfectly all right; they're the aperture to finding out what's right. Science is a self-correcting process." But science is self-correcting only when at least one scientist is willing to question explicit and implicit assumptions used to support theories that have become widely accepted. Most scientists are busy moving forward, building on theories and assumptions that appear to have stood the test of time. Scientific revolutions happen when some laggard stumbles over a cherished assumption for good scientific reasons.

In 2006, while retired, I discovered an enigma in climate science that caused me to put aside almost everything else in my life so that I could work full time, carefully re-examining all the assumptions inherent in greenhouse-warming theory. Several details just did not make physical sense. This ultimately led me to question our fundamental understanding of temperature, heat, and the physical differences between matter and space. I appear to have identified fundamental misunderstandings about what temperature of matter physically is, what heat physically is, how heat flows, and how we should quantify that flow.

I have described elsewhere, in detail, the ozone-depletion theory of climate change, which explains observations of climate change throughout Earth history far more directly, in far greater detail, and with far greater precision than greenhouse-warming theory [*Ward*, 2016; 2017; 2018]. Most climate scientists today summarily dismiss ozone depletion as not involving enough thermal energy to affect climate. They argue that there is a greater <u>amount</u> of thermal energy in the infrared absorbed by greenhouse gases than in the ultraviolet reaching Earth when ozone is depleted. Yet we all known that ultraviolet radiation has a high-enough <u>level</u> of energy to cause sunburn, skin cancer, cataracts, and even mutations of DNA while the total amount of infrared energy in the Universe cannot cause these phenomena. This realization is when it first became clear to me that there appears to be a fundament misunderstanding about the difference between <u>level</u> of radiant energy and <u>amount</u> of radiant energy.

Ozone-depletion theory provides a clear alternative to explain observed global warming, some of which appears to have been caused by humans, but whether this new theory turns out to be verified or not is irrelevant to this paper. This paper is not about a theory. The purpose of this paper is to describe a fundamental misunderstanding in physics about the physical properties of temperature and heat in matter, air, and space and how heat flows through air and space between pieces of matter. I am not proposing some theory that greenhouse-warming theory might be mistaken. I am exposing the harsh reality that greenhouse warming theory is based on mistaken assumptions made since 1822 that are not supported by new insights into the nature of matter and thermal radiation. The results are surprising—even revolutionary. If correct, they make many things that quantum physics tries to explain both physically intuitive and deterministic, something Albert Einstein spent the last 28 years of his life searching for.

The results are also most inconvenient at a time when scientists, by forging consensus, have convinced world leaders to spend trillions of dollars to reduce greenhouse-gas emissions. This is a substantial amount of money when you realize that global gross domestic product in 2017 was only 80 trillion dollars [*CIA*, 2017]. Reducing greenhouse emissions is likely to be a complete waste of money caused by scientists refusing to even consider clear problems with greenhouse-warming theory.

Most leading climate scientists that I talk to, just cannot conceive of the possibility that something “so well-understood” as greenhouse-warming theory could have any flaws. They would rather dismiss the messenger than face this most inconvenient reality, especially at a time when science is under unprecedented attack. If we scientists want science to be valued for informing sound public policy, however, we must move promptly to evaluate emerging evidence that we appear to have convinced world leaders to waste very large amounts of money. Sticking our heads in the sands of consensus is not a viable option and could deal science a mortal blow. Time is of the essence.

## 2. The Physical Properties of Heat Vary with the Temperature of the Emitting Body

Heat is what a body of matter must absorb to get warmer and lose to get cooler. Heat is the spontaneous transfer of thermal energy from a warmer body of matter to a cooler body of matter by thermal conduction within matter, by thermal radiation across air and space, and by convection within a turbulent liquid, gas, or plasma. *Joseph Fourier* [1822] proposed a detailed analytical theory of heat, explaining that “heat, like gravity, penetrates every substance of the universe, its rays occupy all parts of space.” He described heat as a flux, a single numeric “quantity of heat which flows at each point across a given surface” in units of watts per square meter. He pointed out that “all bodies have the property of emitting heat through their surface—the hotter they are, the more [heat] they emit.” Fourier clearly thought that Sun emits the same generic thing called heat as Earth, just a whole lot more of it. He also thought of heat as additive—the greater the amount of heat absorbed, the hotter the body becomes.

Today, nearly two hundred years later, atmospheric scientists still follow Fourier’s formulation despite several problems. First, in 1900, Planck developed empirically a law, which, as described below, clearly shows that the physical properties of heat change substantially with temperature of the radiating body. There is no such thing as generic heat. Second, it is well known that no amount of heat can raise the temperature of the absorbing body to be hotter than the temperature of the emitting body. For example, no amount of infrared radiation from Earth can cause sunburn. Third, it is the difference in temperature between the emitting and absorbing bodies, the temperature gradient, that has the primary influence on how much heat flows between two bodies at any instant in time. This is why curves of warming and cooling are always asymptotic, as shown by the red calculated curve in Figure 1.

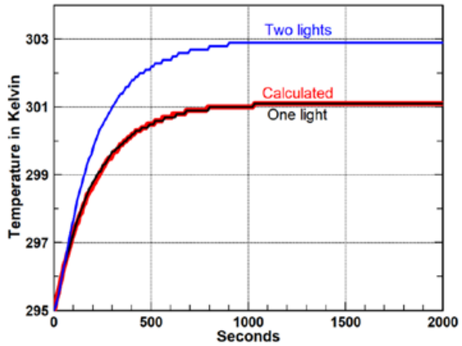


**Figure 1.** The rate of warming, the rate of heat flow, decreases with decreasing difference in temperature forming an asymptotic curve. The black line shows temperature increase of a black, 5-cm-square, 16-gauge metal plate caused by radiation from one 50-watt MR16 ESX picture light placed 90 cm away. The blue line shows similar warming caused by two identical lights. The redline shows the temperature calculated by adding 4.6% times the ending temperature minus the existing temperature at each 10-second interval.

Fourier's ideas appear to give reasonable answers when only small incremental changes in heat are involved and when the range of frequencies is relatively narrow. Fourier's ideas clearly fail when comparing infrared thermal radiation from Earth to the 50-times higher frequency, 50-times higher energy, ultraviolet thermal radiation from Sun.

### 3. The Quantum of Thermal Energy

In 1899, Max Planck concluded that "thermal radiation most probably arises from certain oscillations that take place within molecules or ions" [*Gearhart*, 2008]. Since that time, spectral physicists have observed in great detail that all bonds holding matter together are not rigid

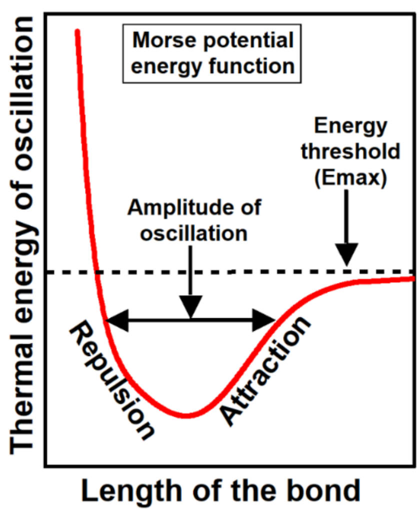


**Figure 2.** Each mode of oscillation of each degree of freedom of each bond holding matter together oscillates as a frictionless molecule-size oscillator. As thermal energy increases, the amplitude of oscillation at each frequency of oscillation increases until the bond reaches an energy threshold Emax and comes apart.

[*Gordon et al.*, 2017]. Each mode of oscillation, of each degree of freedom, of each bond, is observed to oscillate between electromagnetic forces repelling like charges and different electromagnetic forces attracting unlike charges. These molecule-size oscillators, with lengths on the order of $10^{-10}$ meters, are often visualized as behaving according to the Morse potential energy function [*Morse*, 1929] or now more precisely by the Morse/Long-range potential energy function [*Le Roy et al.*, 2009]. As shown in Figure 2, when thermal energy increases, the amplitude of oscillation increases until the bond comes apart at Emax.

Electromagnetic forces are frictionless. Therefore, each oscillator has an energy of oscillation (E) that is simply equal its frequency of oscillation ($\nu$, the Greek letter nu) times a scale factor (h): $E=h\nu$, an equation first postulated by *Planck* [1900]. The important concept here is that energy of oscillation (E) is the same physical thing as frequency of oscillation ($\nu$). In other words, frequency of oscillation ($\nu$) is physically the energy of oscillation (E). To express energy in joules, we multiply frequency of oscillation by h, a scale factor known as the Planck constant—the number of joules of oscillatory energy "contained" in a frequency of one cycle per second—the slope of the line of energy as a function of frequency passing through the origin. In this way, the Planck constant can be estimated easily using light-emitting diodes in a high school physics laboratory [*Rute and Sérgio*, 2014].

In physics, we typically treat energy as a subtle concept [*Coopersmith*, 2010]. We think of heat, for example, as a flux of energy per second, but this avoids having to specify the physical nature of the energy that constitutes heat. $E=h\nu$, on the other hand, says simply that the energy of a single, frictionless oscillator is physically the same thing as its frequency of oscillation. This can be confusing at first because we are not used to thinking of frequency or energy as physical things. They are not material things, but they are things that we know are physically happening around us, even though we cannot see them.

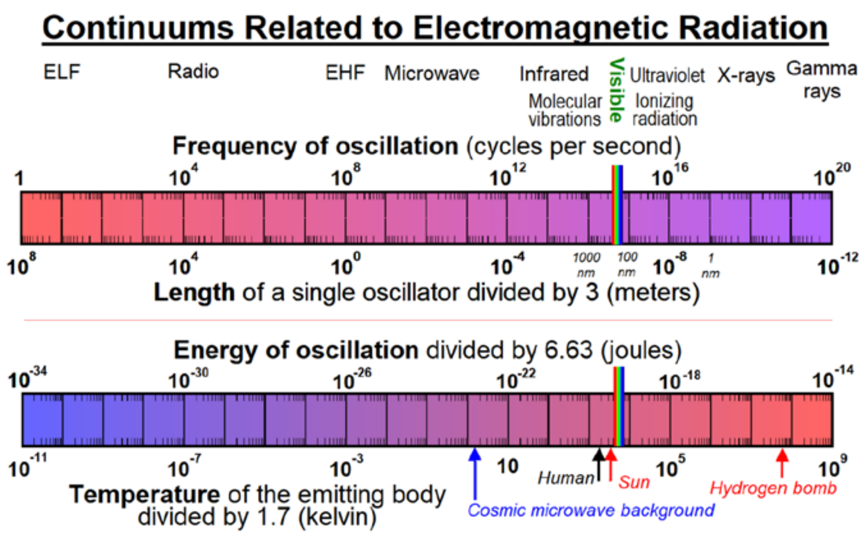


**Figure 3.** Electromagnetic radiation consists of a continuum of frequencies of oscillation. The effective length of an individual oscillator, formerly thought of as wavelength in terms of wave frequency, equals, as a first approximation, the velocity of light ($3\times10^8$ meters per second) divided by frequency of oscillation. The energy of oscillation is equal to frequency of oscillation times the Planck constant ($6.63\times10^{-34}$ joules per cycle per second). The resulting temperature of matter is equal to the frequency of oscillation times the inverse of the Wien displacement constant ($1.7\times10^{11}$ degrees Kelvin per cycle per second).

The tricky part of this is that frequency of oscillation contained in electromagnetic radiation transporting heat is well-observed to be a continuum (Figure 3). This continuum is a very broad range of values that coexist and do not interact in air and space. The continuum extends from extremely low frequency radio signals oscillating at cycles per second ($10^0$), to infrared radiation from Earth whose maximum amplitudes of oscillation (Figure 4) peak around 30 trillion ($3\times10^{13}$) cycles per second, to visible light oscillating at frequencies around 500 trillion ($5\times10^{14}$) cycles per second, and ultimately to gamma rays oscillating at frequencies greater than 100 quintillion ($10^{20}$) cycles per second.

Since frequency ($v$) is a continuum, then energy (E), which equals the Planck constant (h) times a continuum, must also be a continuum. Radiant energy, therefore, is not quantized, although the physical source of radiant energy, these molecule-size oscillators, are physically quantized. For each and every frequency in this continuum, down to some molecular granularity, there is a discrete, molecule-size oscillator on the surface of the radiating body transmitting that frequency just as a radio transmitter transmits its frequency by motion of charge. This means that the smallest chunk into which electromagnetic radiation can be subdivided is a physical, molecule-size oscillator—in effect the atom of electromagnetic radiation or the quantum of electromagnetic radiation. Each oscillator is oscillating at a specific frequency of oscillation, which is a specific energy of oscillation. This energy, $E=hv$, can take on any numeric value throughout the continuum.

This is not our current understanding. $E=hv$ is well-known as the Planck-Einstein relation and is integral to quantum physics where E is thought to be the energy of a photon based on Einstein's interpretation of the photoelectric effect [*Einstein*, 1905]. A photon is thought to be a type of elementary particle, the quantum of electromagnetic radiation. Energy in electromagnetic radiation is thought to be expressed only in terms of integral numbers of photons: $E=nhv$, where n must be an integer. Quantum mechanics is based on the concept that it is the energy itself that is quantized. But radiant energy is well-observed, as shown in Figure 3, to be a continuum. Therefore, radiant electromagnetic thermal energy is not quantized. What is physically quantized in Nature is the individual, molecule-size, frictionless oscillators for each of the modes of oscillation of each of the degrees of freedom of each of the bonds holding matter together.

*Einstein* [1905] proposed the "light quantum," $E=hv$, to explain the photoelectric effect discovered by *Hertz* [1887], who found that when you shine a light on an unoxidized metal surface, electrons flow only when the color of light is above some minimum frequency, above some minimum level of energy ($E=hv$). Above that level, the higher the intensity of the light, the more electrons flow. Below that level, no electrons flow no matter the intensity. Thus $E=hv$ is the minimum level of energy, the minimum frequency of light, that can break the bonds holding an electron on the unoxidized surface of a metal—essentially Emax in Figure 2. We see the same effect with dissociation of molecules such as oxygen ($O_2$) where frequency of oscillation must be within the ultraviolet-C spectrum at a value of around 1237 terahertz (traditionally thought of as a wavelength of 242.4 nanometers), an energy of 5.1 electron volts.

## 4. Planck's Law and the Continuum of Frequency of Oscillation

In 1900, Planck formulated, by trial and error, an equation successfully describing mathematically the observed physical properties of thermal radiation (Figure 4) [*Gearhart*, 2008; *Planck*, 1900]. Thermal radiation is defined as the radiation emitted spontaneously by a body of matter resulting from its temperature. The body is assumed to be black, meaning its surface is a perfect absorber and emitter of radiation, and to be in a state of thermal equilibrium, meaning that the temperature is the same at every point throughout the body such that heat is no longer flowing within the body. This equation, which became known as Planck's law, accurately fit related laboratory data [*Ångström*, 1892; *Langley*, 1888; *Lummer and Pringsheim*, 1899; *Paschen*, 1899; *Rubens and Aschkinass*, 1898] and still fits extensive data available today.

*Planck* [1900] postulated that there must exist "discrete energy elements", E=h*ν*, the energy of oscillation of what he thought of as a "resonator". He introduced h*ν* as the main term for energy in his equation (Figure 4A) and multiplied it by two times the frequency of oscillation squared divided by the velocity of light squared ($2\nu^2/c^2$) to make the units watts per square meter.

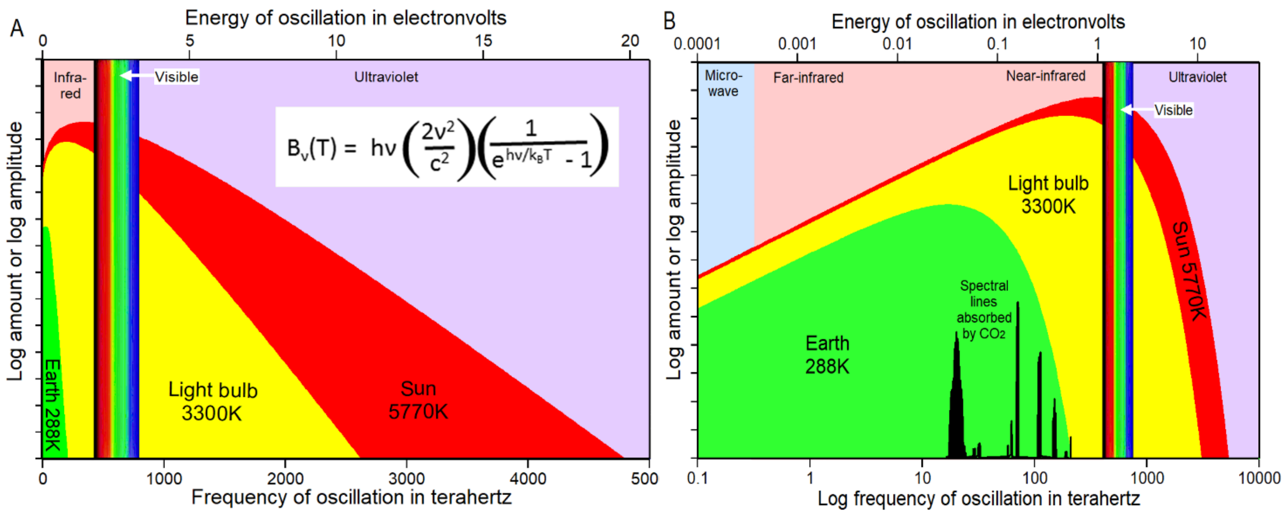


**Figure 4.** Planck's law plotted with linear x-axis on the left and logarithmic x-axis on the right. The vertical black lines on the right are the frequencies of spectral lines of radiation absorbed by $CO_2$.

Planck also uses h*ν* in the exponential term ($h\nu/k_BT$) (Figure 4A), the ratio of joules of oscillatory energy (h*ν*) at the molecular level to joules of energy as a function of absolute temperature ($k_BT$), where $k_B$ is the Boltzmann constant, the number of joules per unit absolute temperature (T).

Planck's law (Figure 4A) calculates, for a body of matter at a specific temperature, the amount of radiant energy at each frequency. Planck's law shows that temperature in matter is the result of a very broad continuum of frequencies of oscillation with several key physical properties. The hotter the body of matter, 1) the broader the continuum of radiated frequencies of oscillation with significant amount, 2) the greater the amount at each and every frequency of oscillation, especially at higher frequencies, and 3) the higher the frequency of oscillation with the greatest amount. No matter how a body of matter is heated, when that body reaches thermal equilibrium, the distribution of frequencies and amounts observed to be emitted are observed to be those described by Planck's law. For example, a body of matter "possesses" a temperature of 3300K only if it contains every single one of the frequencies of oscillation plotted in yellow in Figure 4 and has the amounts (amplitudes) shown in yellow. If the amounts are less, the temperature is lower. If the amounts are more, the temperature is higher. Note that the basic shape of the Planck curve is always the same for thermal radiation and that curves for different temperatures do not intersect except at absolute zero.

Most importantly, Planck's law shows clearly that heat is not a single numeric value of watts per square meter as assumed by Fourier and most scientists today. Heat is a continuum, an infinite series of numeric values. A physical description of the heat that must be absorbed by Earth to become as warm as 3300K is shaded yellow in Figure 4.

We can think of a continuum mathematically as a Fourier series with commas replacing the plus signs and with the number of terms approaching infinity. In a Fourier series, the plus signs implement the principle of superposition, adding up all the single-frequency sinusoidal waveforms to find the solution for a general waveform. This addition is enabled by the bonds holding matter together. In air and space, however, there is no matter and there are no bonds. There is no physical way for the frequencies of oscillation to be added together or to interact with each other in any way. It makes no physical sense, for example, to add red light to blue light. You do not get ultraviolet light. You simply get some red light coexisting with some blue light.

## 5. Amount of Radiation Should Be Amplitude of Oscillation

The data fit by Planck's law were measured by passing light through a prism, which spreads the spectrum out spatially into a rainbow, and then placing a sensor at different angles within each narrow band of color. Infrared radiation does not possess enough energy to penetrate glass. The prism, in that case, was made of halite (rock salt) [*Langley*,1886]. The sensor was typically a thermopile or resistor that changed a very small electrical current, measured in watts, as a function of temperature. Scientists were measuring the thermal effect of a narrow band of radiation on a small piece of matter within their sensor. They thought of this as spectral radiance in units of watts per steradian per meter squared per cycle per second, plotting it on the y-axis as a function of wavelength on the x-axis.

Wavelength, however, and wave frequency (the velocity of light divided by wavelength) both assume Maxwell's wave-theory of light, which cannot apply in air and space as described below. Also described below is how light can display wave-like features such as interference and reflection, but only when in the immediate presence of matter. What scientists were physically measuring was the intensity or brightness of the radiation within a narrow band of frequencies of oscillation ($v$). Energy of light (E) is equal to a constant (h) times frequency ($v$). A small amount of blue light has the same level of energy as a large amount of blue light, while blue light has a higher level of energy than red light. Thus, energy (E) should be plotted on an alternative x-axis shown at the top of the graphs in Figure 4, not on the y-axis.

We all observe that light has two physical properties: color, which is frequency of oscillation, and intensity or brightness, which is amplitude of oscillation. What scientists were measuring physically was a proxy for what we perceive as intensity or brightness, resulting from amplitude of oscillation. Measuring amplitude of oscillation in picometers ($10^{-12}$ meters) was not easy in 1900 and still takes some effort. Thinking of the y-axis as amplitude of oscillation does not change the basic shape of a Planck curve, but a scale factor replacing $2h/c^2$ for the y-axis needs to be calibrated in the laboratory in units of meters per frequency of oscillation cubed. This constant is, most likely, the slope, on a log-log plot (Figure 4B) of a Planck curve at low frequencies. In the meantime, I only show orders of magnitude without specific values on the y-axes in Figure 4.

Planck's law calculates, at a given absolute temperature, this normal amplitude of oscillation as a function of frequency of oscillation. All frequencies of oscillation coexist at all locations and at all times throughout the universe. What varies with increasing temperature of the emitting body and decreasing distance squared is amplitude of oscillation at each frequency of oscillation, ranging from imperceptible to dominant.

## 6. Thermal Radiation Propagates by Resonance

Electromagnetic forces are frictionless. Therefore, each of these tiny, molecule-size oscillators is frictionless. The only known way to increase or decrease the amplitude of oscillation of a frictionless oscillator is by sympathetic resonance. Resonance is a physical phenomenon where one oscillating system "shares" its amplitude of oscillation with another system oscillating at nearly the same frequency. Resonance is what Einstein referred to as "spooky action at a distance" [*Born et al.*, 1971]. Resonance is the observed physical process that quantum physicists seek to explain as quantum entanglement.

Perhaps the simplest example of electromagnetic resonance is how you hear your favorite radio station. The radio station transmits at a specific frequency of oscillation. Transmission is thought to be by motion of charge on the surface of its antenna. You tune your radio receiver to resonate at that frequency, picking the amplitude of oscillation of just that frequency of oscillation out of the broad continuum of all frequencies. This is how signals from hundreds of radio stations, cellphones, WIFI signals, etc. all coexist in the air around us. Amplitude of oscillation is observed to decrease with the inverse square of distance. Your radio, therefore, usually receives the clearest signals from local stations.

Through resonance, two oscillators typically average their amplitudes of oscillation. The oscillator with the greater amplitude "gives up" one-half of the difference in amplitude while the oscillator with the lesser amplitude "absorbs" one-half of the difference in amplitude. Thus amplitude "flows" from higher amplitude to lower amplitude at the same frequency, which, from Planck's law (Figure 4), means from higher temperature to lower temperature. Heat "flows" spontaneously when resonance occurs simultaneously across each and every frequency in the continuum.

Resonance also explains how Planck curves maintain their shape. The amount of amplitude transferred at each frequency is one half of the difference in amplitude at that frequency. Through resonance, amplitudes of oscillation are not physically added together. They are not <u>additive</u> as currently assumed. Rather, they are averaged together at the molecular scale. We could say they are "<u>averative</u>", a word coined here to clarify this distinction. At the macroscopic scale, values of temperature resulting from molecule-size oscillators are also averative. If you take two bodies of matter that are identical in every way except for temperature and connect them together thermally, the resulting temperature, at thermal equilibrium, becomes the average of the initial two temperatures. The greater the difference in temperature, the greater the flux in amplitude and the greater the flux for each particular frequency component of heat.

This averaging is the reason why warming and cooling curves are asymptotic as demonstrated by the red calculated curve in Figure 1. Temperature rises quickly at first when the temperature difference is greatest. Then temperature rises much more slowly, approaching its warmest temperature asymptotically.

By resonance, amplitude flows only from one discrete physical oscillator on the emitting surface to one discrete physical oscillator on the absorbing surface. Conduction of heat via resonance within matter is enhanced by close proximity of independent oscillators. In air and space, resonance is enabled via line-of-sight by electromagnetic radiation, which is transmitted by molecule-scale motion of charge at very high frequencies of oscillation. Frequency of oscillation of radiation is well observed to travel through air and space without any change, even over galactic distances, except for Doppler effects.

Amplitude of oscillation, on the other hand, is well observed to decrease with the square of the distance travelled. This decrease can be understood in terms of the apparent density of molecule-size oscillators on the surface of the near and distant bodies. Over short distances, there is a one-to-one correspondence between oscillators. As distance increases, the distant object looks smaller and smaller. Fewer and fewer molecules on the distant surface are available to resonate with the one molecule on the near surface. Thus, the amplitude transferred by resonance must then be shared by conduction with more and more similar oscillators on the distant surface as they reach thermal equilibrium. In this way, the rate of amplitude transfer slows with the square of increasing distance.

**7. Resonance Is All Around Us**

We perceive visible light from 430 to 770 terahertz (trillion cycles per second, THz) because these are the resonant frequencies of the cells in the cones of our eyes. Three types of cone cells (L, M, and S) are most responsive or sensitive to three different bands of color shown by the lines in Figure 5 [*Stockman et al.*, 1993]. Each triad of cone cells transmits simultaneously three different amplitudes of oscillation encoded in nerve impulses to our brain for each pixel that we see. The size of a pixel is determined by the minimum diameter of a cone cell, which is about 500 nanometers ($5\times10^{-7}$ meters). Our brain, by reassembling the relative intensities of these three signals, can distinguish approximately 10 million different shades of color. This process is the inverse of the process by which a computer sends amplitudes of oscillation of primary red, green, and blue colors (RGB) encoded in 32 bits to a pixel of a computer monitor that can then display more than 16.7 million different shades of color.

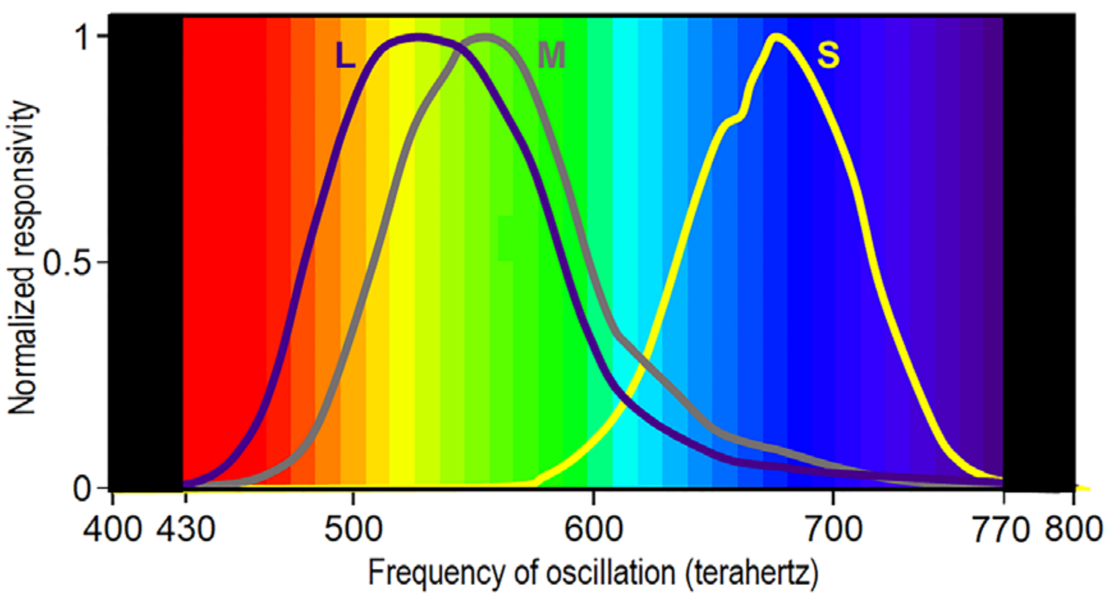


**Figure 5.** Human eyes are generally sensitive to frequencies of 430 to 770 THz as shown by the normalized responsivity of L, M, and S cones (solid lines).

Matter illuminated by electromagnetic radiation containing no frequencies between about 430 THz and 770 THz appears black because these frequencies cannot be detected by human eyes (Figure 5). Thus, black is not a specific frequency; black is what we perceive when there is no visible color. White, on the other hand, is what we perceive when all visible colors simultaneously have substantial amplitudes of oscillation. The more equal the amplitudes of oscillation, the whiter the white.

During resonance, amplitude of oscillation normally increases and decreases over a band of frequencies as shown by the curves in Figure 5, depending on the oscillator's physical structure and its interaction with adjoining oscillators. The breadth of the band is related to the damping of the oscillator often quantified as the quality factor, or Q-factor [*Hecht*, 2016]. It is the slopes of these curves that provide the differences that the brain can use to distinguish about 10 million colors. Scientists are beginning to realize, similarly, that a small number of sensor types involving resonance may be what enables animals to recognize a very wide range of smells and tastes [*Burr*, 2004; *Piesse*, 2015]. The fact that smells and tastes are much more intense at higher temperatures, higher amplitudes of oscillation, suggests that frequency of oscillation and resonance may play the dominant role. In fact, all five senses may be based on resonance.

Thinking in terms of resonance provides a whole new way to understand the flow of heat. For example, when there are clouds in the sky, the bonds holding molecules of water together in the cloud resonate with bonds on Earth's surface. Since the clouds are warmer than deep space, the difference in amplitude of oscillation between Earth and the cloud is smaller than the difference between Earth and deep space. Therefore, the flow of amplitude from Earth to the cloud decreases (Figure 1), making cloudy nights warmer than clear nights.

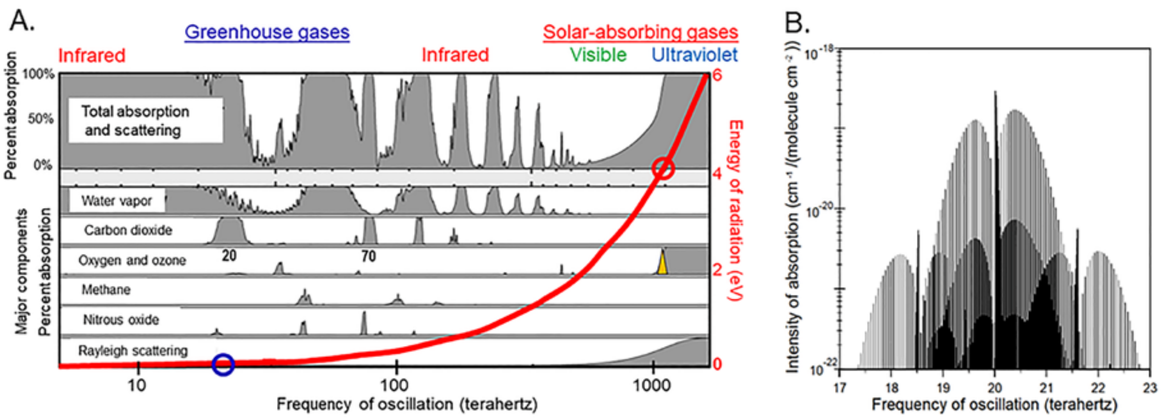


**Figure 6.** Spectral regions absorbed by greenhouse gases are shaded gray. Absorption is along spectral lines too close to see in the shaded areas on the left. Individual spectral lines are plotted on the right for the broad band of absorption for $CO_2$ at 20 terahertz labeled on the left. The red line shows the energy of radiation: E=hν.

### 8. Greenhouse Gases Merely Absorb Spectral Lines of Energy

Spectral physicists document in detail that greenhouse gases merely absorb infrared radiation within narrow bands of frequencies shown by the vertical black lines in Figure 4B and shaded areas in Figure 6A [*Gordon et al.*, 2017]. Furthermore, within these bands, they only absorb narrow spectral lines of energy that are the resonant frequencies of oscillation of the bonds holding all the molecules together (Figure 6B). *Ångström* [1900] concluded that "no more than about 16 percent of earth's radiation can be absorbed by atmospheric carbon dioxide," convincing most physicists at the time that greenhouse-warming theory was not physically possible. Heat radiated by Earth consists of 100% of the frequencies shown in green in Figure 4. If you only absorb 16% of these frequencies, you do not absorb heat in the same way that if you have 16% of a person, you do not have a person. No matter how you propose spectral lines of energy absorbed might cause warming of air, greenhouse gases simply do not absorb heat, they do not absorb enough thermal energy to have much effect on temperature. In the vernacular, they simply do not have enough skin in the game.

Temperature is proportional to how fast atoms are moving relative to each other [*Grossman*, 2014]. The higher the velocity of the atoms, the higher the temperature. In a gas, where each atom or molecule is free to move in any direction, temperature is proportional to the average kinetic energy of translation of all atoms and molecules ($E=½mv^2$). In condensed matter, i.e. solids and liquids, where the atoms are all interconnected by chemical bonds into molecules and molecules are all held together by a variety of intramolecular forces, temperature is proportional to the kinetic energy of oscillation of all of these bonds (Figure 4).

For a greenhouse gas absorbing terrestrial infrared energy to cause warming of air, one must assume that the kinetic energy of oscillation absorbed into the bonds is converted to kinetic energy of translation during myriad collisions. This conversion has never been quantified in the laboratory but cannot be very efficient. Furthermore, carbon dioxide, for example, makes up only 0.04% of the gas molecules in air and thus would have to share their kinetic energy with the other 99.96% of the molecules. In addition, by Planck's law (Figure 4), radiation from Earth does not contain high enough amplitudes of oscillation at all frequencies of oscillation to warm Earth. A body of matter cannot physically be warmed by its own radiation.

It has been assumed ever since *Tyndall* [1859] first observed that greenhouse gases absorb infrared energy, that, therefore, they warm air. This assumption has never been verified by experiment and appears to be physically impossible.

The greatest warming of air observed in Earth's atmosphere is daily in the stratosphere where solar radiation maintains the temperature of the stratopause approximately 60 K warmer than the temperature of the tropopause. This warming is caused by solar ultraviolet-C radiation dissociating oxygen and other gas species and solar ultraviolet-B dissociating ozone and other gas species. Upon dissociation, the pieces of the gas molecule fly apart at high velocity, converting all the energy stored in the bond directly into air temperature. Dissociation of oxygen and ozone occur in the endless Chapman cycle until all ultraviolet-C and most ultraviolet-B is absorbed above the tropopause. Dissociation and ionization are the only ways known that gases absorbing radiant energy can become warmed.

A common claim is that Earth would be 33 K colder were it not for greenhouse gases. These back-of-the-envelope calculations do not include the effect of the stratosphere. We observe clearly that the stratosphere forms an electric blanket around Earth. Electric in the sense that the energy to warm the blanket comes from a distant source, Sun, not from the body under the blanket, Earth. It is the stratosphere that is observed to keep Earth warm—not greenhouse gases.

## 9. Light Cannot Physically Travel as Waves, Nor as Particles

*Maxwell* [1865] developed a series of equations that seemed to describe accurately waves of light traveling through space at the speed of light via electric and magnetic fields. Yet Hooke, Fresnel, and others recognized that waves are the deformation of matter and there is no matter in space to deform. They proposed, therefore, that waves in space must travel in a luminiferous aether, which was thought to be some invisible form of matter. Numerous physicists in the $19^{th}$ century tried to demonstrate the presence of a luminiferous aether, but *Michelson and Morley* [1887] showed, in a definitive experiment accepted by most physicists, that such an aether does not exist.

There are other issues with light waves. For example, light that we see travels from point to point with all the energy traveling along what we think of as rays, whereas waves would smear the energy out over space, blurring our vision. Furthermore, the higher the wave-frequency of seismic waves, the greater the attenuation with distance. Light has frequencies $10^{14}$ times higher than the frequencies of seismic waves. There is no material stiff enough to allow such high frequencies to propagate as waves.

Yet to this day, most physicists are convinced that light travels as waves or as wave-particle duality. They rationalize that electromagnetic waves must be different, in some way, from waves in matter. The difference is in what we mean by frequency. When I say light travels as frequency, people always respond “yes but frequency equals the velocity of light divided by wavelength.” They are talking about wave frequency. I am talking about frequency of oscillation—something totally different. Wave frequency travels with some velocity and the dominant frequencies typically decrease in frequency with distance. Frequency of oscillation is well observed not to change with distance, even over galactic distances.

Light does appear to have a velocity that Maxwell concluded is equal to one divided by the square root of the product of two constants: the vacuum permittivity, which is the resistance to forming an electric field, times the magnetic permeability, which is the ability to form a magnetic field [*Maxwell*, 1873]. What we think of as velocity of light may simply be the very short but finite interval of time that it takes for what we think of as an electric field to induce a magnetic field to begin to induce an electric field again. It is this very rapid interaction that appears to enable resonance.

*Newton* [1704] argued that light must be particles because rays of light are very straight. *Einstein* [1905] showed that the photoelectric effect, which cannot be explained by Maxwell’s wave equations [*Maxwell*, 1873], can be explained by assuming the energy of light is quantized as $E=h\nu$, ultimately thought of as the energy of a photon, a particle of light. While Einstein did not express it this way, it seemed logical that an incoming particle would knock an electron loose much like a billiard ball. To this day, no one has explained physically, in detail, how a photon interacts with a gas molecule nor how a shower of photons interacts with a gas molecule to transfer the spectral lines of energy observed in Figure 6B. The clearest problem with the photon concept is, as explained above, that frequency and, therefore, energy of electromagnetic radiation are continua. If $E=h\nu$, then energy is not quantized. It is the source of energy that is quantized—the myriad of tiny physical oscillators. Light, other electromagnetic radiation, and heat all appear to travel by resonance.

## 10. But What About the Wave-Like Features of Light?

For most physicists, the strongest argument that light travels as waves is that light displays properties such as interference, reflection, refraction, diffraction, dispersion, and birefringence traditionally explained by wave-theory. These properties, however, are not observed in space. They are observed only when light impinges on matter—is in the immediate vicinity of matter. It is the bonds holding the surface of matter together that enable the interaction of frequencies.

Every mode of oscillation, of each degree of freedom, of each bond on the surface of any object that we see is transmitting a frequency of oscillation based on the temperature of the object. In the temperature range in which humans live, all frequencies of oscillation with significant amplitude of oscillation are in the infrared and microwave frequency bands (Figure 4). When visible light containing much higher frequencies of oscillation shines on matter, most frequencies of oscillation are absorbed into the matter but some cause molecules on the surface to resonate at specific frequencies that constitute the color of the surface. This color may be determined by pigments, dyes, or structural coloration. These frequencies then resonate with the cones in our eyes causing us to see that color.

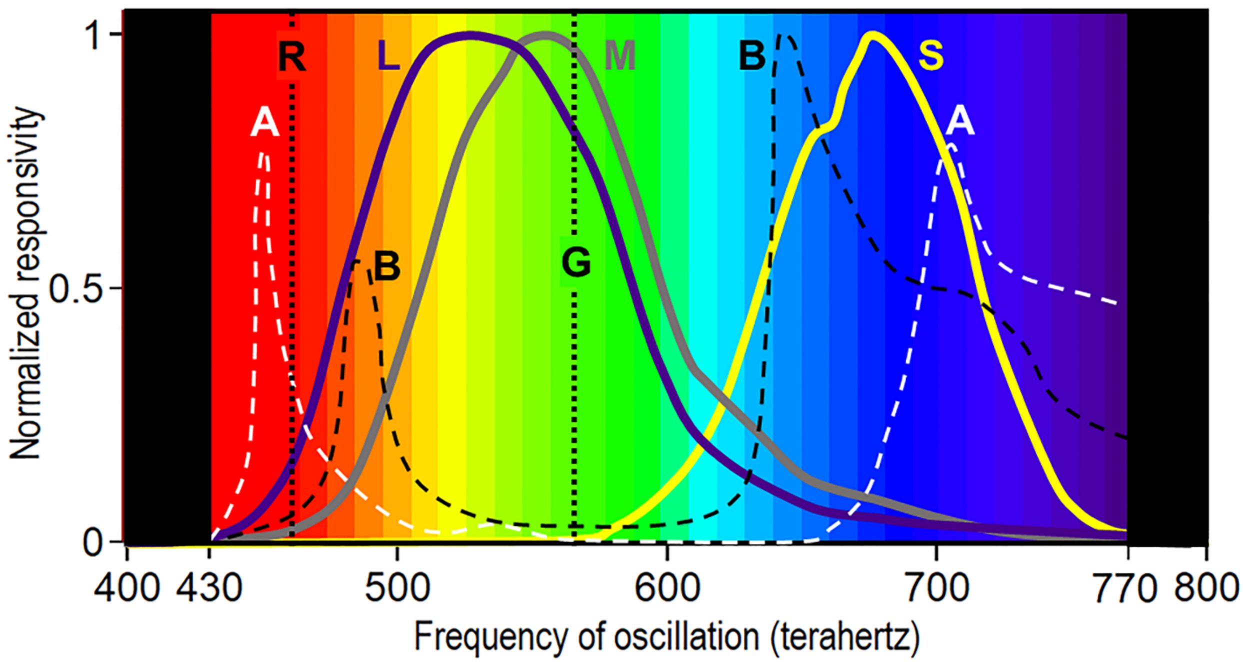


**Figure 7.** Human eyes are generally sensitive to frequencies of 430 to 770 THz as shown by the normalized responsivity of L, M, and S cones (solid lines). The dashed lines show the responsivity of chlorophyll-A and chlorophyll-B. The dotted lines show the frequencies typical of red and green laser pointers. Note how much more sensitive the human eye is to green lasers than to red lasers.

Figure 7 shows the response of human eyes to color shown in Figure 5 with the addition of the responsivity of chlorophyll-A and chlorophyll-B, which are green pigments found in cyanobacteria and the chloroplasts of algae and plants. Reds and blues are strongly absorbed into the chlorophyll providing the energy for plants to grow, while greens oscillate on the surface, transmitting the green color where it can resonate with the cones in our eyes. Thus, incoming light is not reflected, it is absorbed through resonance by pigments or dyes and selectively retransmitted as color.

Classical laws of reflection, refraction, and interference rely on the Huygens-Fresnel principle, developed in 1678 and 1818, which assumes that every point to which light reaches becomes the source of a spherical wave of light. This is similar to retransmission discussed above except retransmission occurs only on the surface of matter, not at every point in space and each bond oscillator has an orientation, a correction added to the Huygens-Fresnel principle by *Miller* [1991].

There are many details to work out, but it appears that the wave-like properties of light may be more precisely explained by retransmission than by classical wave theory.

**11. Some Implications**

Recognizing that temperature and heat are the result of a broad continuum of frequencies of oscillation of all the bonds holding matter together, that thermal energy is not quantized but its molecule-size sources are, and that amplitude of oscillation at each discrete frequency of oscillation travels by resonance, leads to several important insights.

The bonds holding matter together contain substantial thermal oscillatory energy. The hotter the matter, the higher the frequencies of oscillation, the greater the energy of oscillation, the higher the amplitudes of oscillation, and the higher the frequencies with the greatest amplitudes of oscillation. As the temperature of matter approaches absolute zero, the energies, frequencies and amplitudes of oscillation all approach zero. Frequency and therefore energy also increase with decreasing length of a bond. Thus, atomic bonds contain much greater oscillatory energies than molecular bonds. Molecular bond energy flows as heat by resonance and is converted directly into air temperature when the bonds come apart by dissociation. One way to look at Einstein's famous equation $E=mc^2$ is that it says that matter physically consists of a very large number of bonds that contain very large amounts of oscillatory energy. The more matter, the more bonds, the more energy.

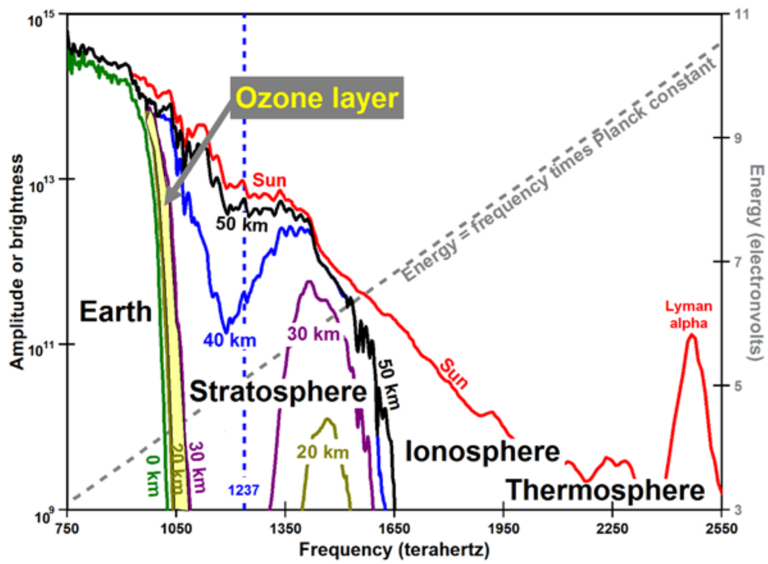


**Figure 8.** The highest frequency, highest energy solar radiation is absorbed high up in the atmosphere. The red line shows the amplitude of solar radiant energy received at the top of Earth's atmosphere. The other solid lines show, in effect, how much of that solar radiation has been absorbed at different altitudes labeled. The dashed blue line shows the frequency (1237 THz) where oxygen is dissociated. The dashed gray line show the energy of that frequency of radiation.

Electromagnetic radiation, light, is thought to travel through an electromagnetic field as waves or particles at the speed of light. A field is thought to be a physical quantity, either a number or a tensor, that can be measured at each point in space and time, mapping out a distribution in air or space—what *Feynman et al.* [1963] called a "condition in space". Thinking in terms of resonance, we can now understand that an electromagnetic field is nothing more than a three-dimensional map of what an appropriate sensor would measure if it were placed at that point and resonated with the source of the radiation. Thus, the only physical thing that needs to exist in a field and in radiation is the ability to foster resonance. We think of an electric field as the result of stationary charge and a magnetic field as the result of moving, oscillating, charge. Resonance only occurs when the frequency of oscillation in the emitting oscillator is very close to the frequency of oscillation in the absorbing oscillator and when there is a difference in amplitude of oscillation. Precisely how resonance occurs over very short to galactic distances, how resonance has a time delay with distance so that it appears to travel at the speed of light, and how resonance changes with time are all things we should be able to observe and quantify in the laboratory.

The Morse potential energy function posits that a molecule is dissociated when the thermal energy of oscillation reaches an energy threshold in an asymptotic manner (Emax in Figure 2). There is another possibility. Figure 8 shows the altitude above which solar radiation of different frequencies is absorbed in Earth's atmosphere [*DeMore et al.*, 1997]. The blue dashed line at a frequency of 1237 THz is the frequency, the level of energy observed to cause dissociation of molecular oxygen into two atoms of oxygen. Note that absorption in the stratosphere at altitudes from 20 to 50 km is nearly symmetric about this frequency. Thus, it is not all frequencies above 1237 THz that cause dissociation, it is frequencies in the vicinity of 1237 THz. This suggests that the bond resonates in the vicinity of 1237 THz, suddenly causing larger amplitudes of oscillation than the asymptotic manner posited by the Morse potential energy function.

It is the oscillation of all the bonds holding matter together that enable resonance. We think of the oscillation as being driven by the forces of repulsion of like charges and the forces of attraction of opposite charges. The question is, what is charge, or, more directly, what enables bond oscillation?

## 12. Conclusions

Heat is what a body of matter must absorb to increase its temperature and must emit to decrease its temperature. Both temperature of matter and heat are the result of a very broad continuum of frequencies of oscillation of all the bonds holding matter together as described by Planck's law. A body of matter at a given temperature is observed to radiate all of the frequencies of oscillation at the amplitudes of oscillation described by Planck's law. Heat is the continuum of amplitudes and frequencies described by the difference in two Planck curves for the starting and ending temperature.

Greenhouse gases absorb only some spectral lines of radiation that are the resonant frequencies of the bonds holding the molecules together. They do not absorb heat. Carbon dioxide, for example, absorbs less than 16 percent of the frequencies of oscillation radiated by Earth. What carbon dioxide absorbs cannot physically make air much warmer. Furthermore, radiation from a body of matter cannot in any way warm that body as shown by Planck's law.

The problem with greenhouse-warming theory is that, contrary to current thinking, heat cannot be described adequately by a single number of watts per square meter, and heat is not additive. Temperature and heat are averative. If you take two bodies of matter that are identical in every way except for temperature and connect them together thermally, the resulting temperature, at thermal equilibrium, becomes the average of the initial two temperatures. Heat flows by resonance where two discrete oscillators at nearly the same frequency of oscillation average amplitudes of oscillation. The greater the difference in amplitude, which by Planck's law means the greater the difference in temperature, the greater the amount of heat that flows per unit time.

These misunderstandings regarding temperature and heat were first quantified by Fourier in 1822 and form the foundation of greenhouse-warming theory. It is now clear that greenhouse-warming theory is not physically possible and that observed global warming is explained far more directly, in far greater detail, and with far greater precision by observed ozone depletion caused by humans and by volcanic eruptions.

Scientists, in their well-meaning drive to forge consensus around greenhouse-warming theory in order to convince political leaders to spend trillions of dollars to reduce greenhouse-gas emissions, appear to have made a mistake. It is extremely important to the world and to good science that these scientists promptly address such fundamental misunderstandings and evaluate the best route forward. Time is of the essence.

**Acknowledgements**: Special thanks for thoughtful reviews by James Herriot, David Laing, Bert Raynes, Adrienne Ward, Linton Wildrick, and Karen Wenrich. This work benefited from interaction with more than 5000 scientists over a dozen years. Funding was provided by my children's inheritance. Author declares no competing interests. Data plotted are available in Supplementary Information and on Internet as referenced.

**References:**

Ångström, K. (1892), Untersuchungen über die spektrale Verteilung der Absorption im ultraroten Spektrum, in *Physikalische Revue*, edited, pp. 597-623. ISBN:978-1248351277

Ångström, K. (1900), Ueber die Bedeutung des Wasserdampfes und der Kohlensäure bei der Absorption der Erdatmosphäre, *Ann. Phys.*, *308*(12), 720-732. https://doi.org/10.1002/andp.19003081208. In English at https://ozonedepletiontheory.info/Papers/Angstrom1900-English.pdf.

Born, M., A. Einstein, and H. Born (1971), *Born-Einstein Letters: Friendship, politics, and physics in uncertain times*, 235 pp., Macmillan, ISBN:978-1403944962

Burr, C. (2004), *The emperor of scent: A true story of perfume and obsession*, 352 pp., Random House, ISBN:978-0375759819

CIA (2017), The world factbook, *https://www.cia.gov/library/publications/the-world-factbook*.

Coopersmith, J. (2010), *Energy, the Subtle Concept: The discovery of Feynman's blocks from Leibniz to Einstein*, 400 pp., Oxford University Press ISBN:978-0198716747

DeMore, W., S. Sander, D. Golden, R. Hampson, M. Kurylo, C. Howard, A. Ravishankara, C. Kolb, and M. Molina (1997), Chemical kinetics and photochemical data for use in stratospheric modeling, Evaluation number 12, p. 260, Figure 7. *Rep.*, Jet Propulsion Lab., California Inst. of Tech., Pasadena, https://jpldataeval.jpl.nasa.gov/pdf/Atmos97_Anotated.pdf.

Einstein, A. (1905), Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt, *Ann. Phys.*, *322*(6), 132-148. https://doi.org/10.1002/andp.19053220607. In English at https://en.wikisource.org/wiki/A_Heuristic_Model_of_the_Creation_and_Transformation_of_Light.

Feynman, R. P., R. B. Leighton, and M. Sands (1963), *Feynman lectures on physics. vol. 2: Mainly electromagnetism and matter*, 592 pp., Addison-Wesley, http://www.feynmanlectures.caltech.edu/II_toc.html,

Fourier, J. (1822), *The Analytic Theory of Heat.* *https://archive.org/details/analyticaltheor00fourgoog*,

Gearhart, C. A. (2008), Max Planck and black-body radiation, in *Max Planck: Annalen Papers*, edited by D. Hoffmann, pp. 395-418, Wiley-VCH. ISBN:978-3527408191
Gordon, I. E., L. S. Rothman, C. Hill, R. V. Kochanov, Y. Tan, P. F. Bernath, M. Birk, V. Boudon, A. Campargue, and K. Chance (2017), The HITRAN2016 molecular spectroscopic database, *J. Quant. Spectrosc. Radiat. Transfer*, *203*, 3-69. https://doi.org/10.1016/j.jqsrt.2017.06.038
Grossman, J. C. (2014), Thermodynamics: Four laws that move the Universe, The Great Courses, Course 1291. https://www.thegreatcourses.com/courses/thermodynamics-four-laws-that-move-the-universe.html
Hecht, E. (2016), *Optics*, 720 pp., Pearson, ISBN:978-0133977226
Hertz, H. (1887), Ueber einen Einfluss des ultravioletten Lichtes auf die electrische Entladung, *Ann. Phys.*, *267*(8), 983-1000. https://doi.org/10.1002/andp.18872670827
Langley, S. P. (1886), LIII. Observations on invisible heat-spectra and the recognition of hitherto unmeasured wave-lengths, made at the Allegheny observatory, *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, *21*(132), 394-409. https://doi.org/10.1080/14786448608627864
Langley, S. P. (1888), LIX. The invisible solar and lunar spectrum, *Philosophical Magazine Series 5*, *26*(163), 505-520. https://doi.org/10.1080/14786448808628306
Lummer, O., and E. Pringsheim (1899), Die Vertheilung der Energie im Spectrum des schwarzen Körpers und des blanken Platins; Temperaturbestrimmung fester glühender Körper, *Verhandlungen der Deutchen Physikakischen Gesellschaft*, *1*, 215-235. https://babel.hathitrust.org/cgi/pt?id=coo.31924056107224;view=31924056107221up;seq=31924056107229.
Maxwell, J. C. (1865), A dynamical theory of the electromagnetic field, *Phil. Trans. R. Soc. London*, *155*, 459-512. https://doi.org/10.1098/rstl.1865.0008
Maxwell, J. C. (1873), *A treatise on electricity and magnetism*, 560 pp., Clarendon Press, Oxford, http://archive.org/details/electricandmagne01maxwrich.
Michelson, A. A., and E. W. Morley (1887), On the relative motion of the earth and the luminiferous ether, *Am. J. Sci.*, *34*(203), 333-345. https://doi.org/10.2475/ajs.s3-34.203.333
Miller, D. A. (1991), Huygens's wave propagation principle corrected, *Optics letters*, *16*(18), 1370-1372. https://doi.org/10.1364/OL.16.001370
Newton, I. (1704), *Opticks: or a treatise of the reflections, refractions, inflections and colours of light*, William Innys, London, https://archive.org/details/opticksortreatis1730newt,
Paschen, F. (1899), On the Distribution of the Energy in the Spectrum of the Black Body at Low Temperatures, *The Astrophysical Journal*, *10*, 40-57. https://doi.org/10.1086/140607
Piesse, G. W. S. (2015), *The art of perfumery: Method of obtaining the odors of plants*, 368 pp., CreateSpace Independent Publishing Platform, ISBN:978-1979326445
Planck, M. (1900), Entropie und Temperatur strahlender Wärme, *Ann. Phys.*, *306*(4), 719-737. https://doi.org/10.1002/andp.19003060410
Rubens, H., and E. Aschkinass (1898), Observations on the absorption and emission of aqueous vapor and carbon dioxide in the infra-red spectrum, *Astrophys. J.*, *8*, 176-192. https://doi.org/10.1086/140516
Rute, M., and P. Sérgio (2014), Classroom fundamentals: measuring the Planck constant, *Science in School*(28, Spring, http://ScienceInSchool.org/sites/default/files/teaserPdf/issue28_planck.pdf), 28-33.

Stockman, A., D. I. MacLeod, and N. E. Johnson (1993), Spectral sensitivities of the human cones, *JOSA A*, *10*(12), 2491-2521. https://doi.org/10.1364/JOSAA.10.002491
Tyndall, J. (1859), On the transmission of heat of different qualities through gases of different kinds, *Notices of the Proceedings of the Royal Institution of Great Britain*, *3*, 155-158. https://archive.org/details/noticesofproceed103roya.
Ward, P. L. (2016), *What really causes global warming? Greenhouse gases or ozone depletion?*, 237 pp., Morgan James Publishing, New York, ISBN:978-1-63047-798-1
Ward, P. L. (2017), Ozone depletion explains global warming, *Current Physical Chemistry*, *6*(4), 275-296. https://doi.org/10.2174/1877946806999160629080145
Ward, P. L. (2018), https://WhyClimateChanges.com.