Experimental evidence for why greenhouse gases cannot be the primary cause of global warming

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Global mean surface temperatures warmed >1 ºC since 1950, and warming from 1969 to 1998 may well have been caused by humans, but there are numerous reasons to question whether greenhouse gases can physically be the primary cause. Greenhouse-warming theory has never been verified by experiment, a cornerstone of the scientific method. This paper describes a simple, reproducible experiment showing that air containing more than 23 times normal CO_2 concentrations is warmed by absorbing infrared radiation only slightly more than normal air. Infrared radiant energy is absorbed into the bonds that hold each molecule of CO_2 together. This energy must then be converted by collision to translational velocity and partitioned among 2500 other gas molecules to increase air temperature. The efficiency and effects of such conversions have never been determined.

Nearly all countries in the world committed under the Paris Agreement (UN, 2017) to work together to reduce greenhouse-gas emissions with the aim of "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels." The problem is that observed increases in atmospheric concentrations of carbon dioxide (CO_2) have never been shown in a scientific experiment to actually cause several degrees of global warming as is widely assumed. This is odd. As Steven Chu, Nobel laureate in Physics and former Secretary of Energy, puts it: "In the scientific world … the final arbitrator of any point of view are experiments that seek the unbiased truth." Greenhouse-warming theory is based on several assumptions concerning thermal energy and radiation that have never been demonstrated by experiment. This fundamental breakdown in the scientific method needs to be evaluated and corrected soon. Time is of the essence. Otherwise, trillions of dollars could be wasted.

Greenhouse-warming theory: The Intergovernmental Panel on Climate Change (IPCC) defines the greenhouse effect as: "*The infrared radiative effect of all infrared-absorbing constituents in the atmosphere. Greenhouse gases, clouds, and (to a small extent) aerosols absorb terrestrial radiation emitted by the Earth's surface and elsewhere in the atmosphere. These substances emit infrared radiation in all directions, but, everything else being equal, the net amount emitted to space is normally less than would have been emitted in the absence of these absorbers* *because of the decline of temperature with altitude in the troposphere and the consequent weakening of emission. An increase in the concentration of greenhouse gases increases the magnitude of this effect*" (Planton, 2013). This absorption and re-radiation of terrestrial infrared radiation is thought to ultimately lead to global warming quantified as the climate sensitivity, "*the equilibrium (steady state) change in the annual global mean surface temperature following a doubling of the atmospheric equivalent carbon dioxide concentration*" (Planton, 2013) and thought, "with high confidence", to be in the range of 1.5 to 4.5 °C (IPCC, 2013). Climate scientists calculate climate sensitivity by assuming that observed increases in concentrations of greenhouse gases are the primary cause of all observed global warming.

The physical link between observed absorption of terrestrial infrared radiation and anticipated climate sensitivity is thought to be provided by one or more of the following five mechanisms:

1. direct heating of air,
2. direct heating of air that slows the rate of heat loss from Earth,
3. re-radiation of absorbed energy that slows the rate of heat loss from Earth,
4. re-radiation of absorbed energy back to Earth where it is absorbed and causes warming of Earth, and
5. climate feedbacks, which are interactions "*in which a perturbation in one climate quantity causes a change in a second, and the change in the second quantity ultimately leads to an additional change in the first*" (Planton, 2013).

The purpose of this paper is to examine direct observations and experimental evidence for how heat associated with climate actually flows and for how effective each of these five widely assumed mechanisms can be for producing observed increases in global temperature.

The physical basis for temperature: "*By measuring temperature, we're measuring how fast the atoms in the material are moving. The higher the average velocity of the atoms, the higher the temperature of the material*" (Grossman, 2014). Temperature of a gas is proportional to the average kinetic energy of translation of all the molecules making up the gas, where the translational kinetic energy of each molecule is equal to one-half its mass times its translational velocity squared. The hotter the gas, the higher the average translational velocity. Decrease the temperature of the gas towards absolute zero, the velocities of the molecules approach zero.

Temperature of a body of matter, on the other hand, results from oscillation of all the bonds that hold matter together as described by Planck's law (Figure 1). Planck

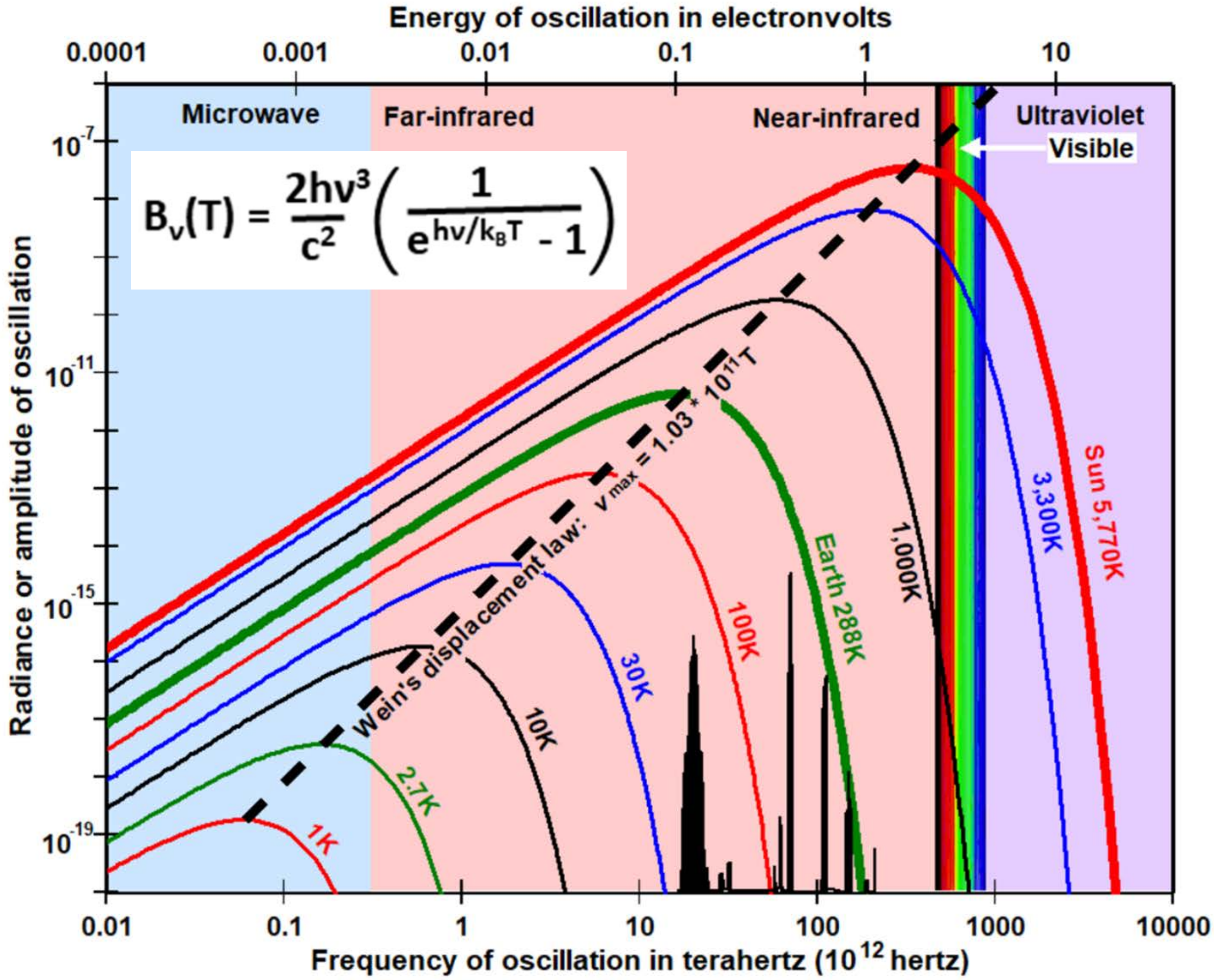

Figure 1. Planck's law describes radiation emitted as a function of the temperature by a black body at thermal equilibrium. The vertical black bars show the frequencies of oscillation absorbed by CO_2 as also shown in Figures 2 and 3. Variables are radiance (B), Planck's constant (h), frequency of oscillation (v), velocity of light (c), the Boltzmann constant (k_B) and temperature (T).

(1900) developed empirically a mathematical equation that describes thermal radiation observed to be emitted by a black body of matter at thermal equilibrium as a function of its temperature. This thermal radiation consists of a broad continuum of frequencies of oscillation, each with a unique amplitude of oscillation that increases with increasing temperature (Figure 1). The frequency with the maximum amplitude of oscillation (v_{max}) also increases as a function of temperature according to Wien's displacement law where v_{max}=1.03*10^{11} T. Increase the temperature of matter, these frequencies and amplitudes of oscillation increase. Decrease the temperature towards absolute zero, these frequencies and amplitudes of oscillation approach zero.

This thermal radiation is transmitted into air or space by oscillation of all the bonds on the surface of the radiating matter, which are thought to induce, by charge-acceleration and/or dipole oscillation, an electric field just above the surface, which induces a magnetic field, which induces an electric field, ad infinitum, forming electromagnetic radiation. Thus, the broad continuum of frequencies and amplitudes plotted in Figure 1 for observed radiation also shows the broad continuum of frequencies and amplitudes of oscillation on the surface of the radiating body. In this way, the electromagnetic field provides the physical means to transmit the thermal energy contained in this broad continuum of frequencies and amplitudes of oscillation through air and space via line of sight. Each frequency propagates independently in the same manner as a single-frequency radio signal propagates from transmitter to receiver.

Frequencies are observed to travel even galactic distances through air and space without any interaction or change other than Doppler effects, while amplitudes of oscillation are observed to decrease proportional to the inverse square of the distance travelled. When these frequencies and amplitudes are absorbed by matter, they typically increase the temperature of the absorbing matter to some value that is observed to be always less than or equal to the temperature of the radiating matter.

Note for Planck's equation in Figure 1 that radiance is a function of frequency of oscillation cubed (ν^3). Note that frequencies of oscillation radiated by Earth (thick green line) include a very broad continuum extending in the plot from less than 0.01 terahertz (trillion cycles per second) to more than 135 terahertz. Note that bodies with higher temperatures are observed to emit much higher frequencies of oscillation than bodies with lower temperatures, and that warmer bodies emit higher radiance than cooler bodies at each and every frequency.

Visible light has two physical characteristics: color and brightness of this color, which are, in matter, frequency of oscillation and amplitude of oscillation. We think of intensity or brightness as radiance with units including watts. As explained in detail in the supplemental materials, however, radiance as measured is actually a proxy for amplitude of oscillation in picometers on the surface emitting the radiation decreased by one over the square of the distance travelled from the radiating surface.

While a body might absorb radiation from any number of sources, each with a different distribution of frequencies, the body's temperature is not strictly defined until, through absorption and conduction, the body has reached thermal equilibrium with the specific frequency distribution shown by a Planck curve for that temperature. All frequencies of oscillation, each at the radiance shown, must be present. The net thermal energy, the net heat that must flow to raise the temperature of a body from T_1 to T_2, is most accurately described by the region between the Planck curves for T_1 and T_2, representing a broad continuum of frequencies of oscillation, each with a specific amplitude of oscillation.

Planck's empirical law (Figure 1) shows unequivocally that the temperature to which the absorbing matter can be raised is determined solely by the broad continuum of frequencies and amplitudes of oscillation contained in the radiation, which is determined by the temperature of the radiating body, with the amplitudes of oscillation decreased by one over the square of the distance travelled. Note that the temperature to which the absorbing matter can be raised is not a function of how much radiation exists, as currently assumed and calculated in greenhouse-warming theory and in thermodynamics in general. The amount or flux of radiation does determine how long it will take to heat a given body, but the Planck distribution of frequencies and amplitudes determines the maximum temperature to which the absorbing body can be raised.

What is absorbed by greenhouse gases? Tyndall (1859) demonstrated in the laboratory that compound gases, containing three or more atoms per molecule, absorb terrestrial infrared radiation. These greenhouse gases, however, only occur in small concentrations: water (0.4% on average), carbon dioxide (400 ppm), methane (1800 ppb), nitrous oxide (328 ppb) and ozone (337 ppb) (Figure 2) (Blasing, 2016).

Molecules of these gases are observed to absorb only very specific frequencies of oscillation from the broad continuum of frequencies making up terrestrial radiation. Spectral physicists have measured these spectral lines of absorption in considerable detail in the laboratory (Rothman et al., 2013). The gray-shaded areas in Figure 2 show the wavelength bands of absorption for key greenhouse gases. Figure 3 shows individual spectral lines of absorption within the major absorption band for CO_2 centered near 14.9 micrometers. These spectral lines are clearly observed by spectral physicists to be the resonant frequencies of all the normal modes, of all the degrees of freedom, of all the bonds holding the CO_2 molecule together. Compound gases containing

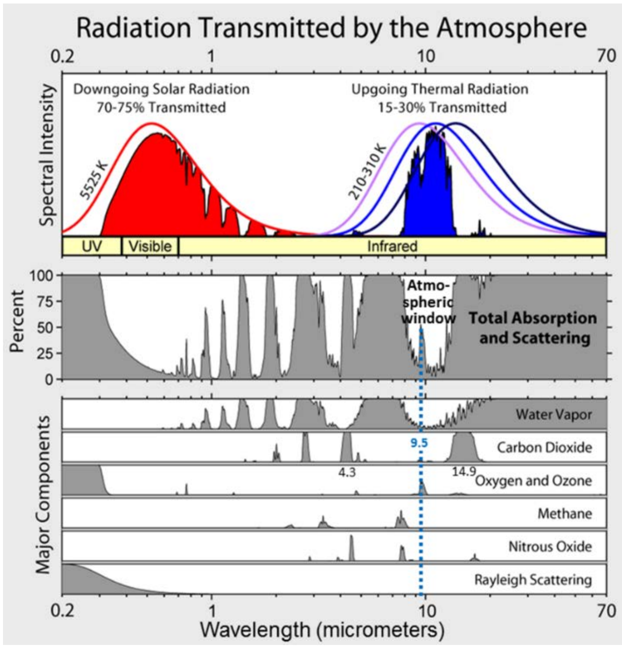

Figure 2. Absorption bands for greenhouse gases in Earth's atmosphere from Rohde (2017).

three or more atoms are greenhouse gases precisely because they contain more bonds with many more degrees of freedom, such as symmetric and asymmetric stretching, scissoring, rocking, wagging and twisting (Molecular vibration, 2017), storing more thermal energy than simple gases making up most of Earth's atmosphere. These spectral lines are so unique for each type of molecule that spectral physicists use them to identify gas molecules from near at hand to very distant galaxies. Atmospheric radiative transfer computer codes calculate total absorption by integrating across the area under these spectral lines.

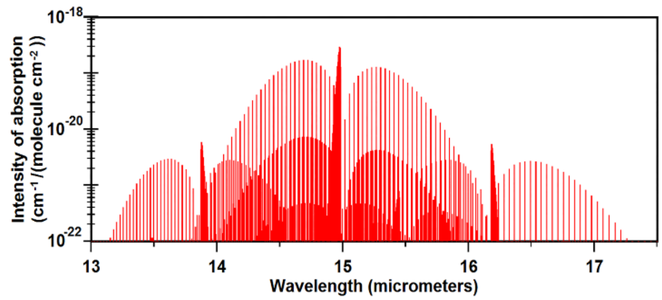

Figure 3. Spectral lines of absorption for CO_2 (Rothman et al., 2013).

The vertical black bars in Figure 1 show the frequencies absorbed by carbon dioxide, the same as the shaded areas for CO_2 in Figure 2 and the spectral lines shown in Figure 3. The relative heights of these lines are based on observations, but the absolute height is arbitrary to fit under the green line simply to show that CO_2 absorbs less than 20% of the frequencies emitted by Earth. Ångström (1900) concluded "*from these studies and calculations, it is clear, first, that no more than about 16 percent of [the frequencies making up] earth's radiation can be absorbed by atmospheric carbon dioxide, and secondly, that the total absorption is very little dependent on the changes in the atmospheric carbon dioxide content, as long as it is not smaller than 0.2 of the existing value.*" Thus, experimental data show that CO_2 only absorbs less than about 16% of the frequencies of thermal oscillations radiated by Earth, yet by Planck's law, a body of solid matter must possess 100% of the frequencies of oscillation shown under the green line in Figure 1, at the amplitudes of oscillation shown, in order to be heated to the temperature of Earth.

It has been widely assumed since Tyndall's experiments that, by the conservation of energy, thermal radiant energy absorbed by CO_2 must heat air. Yet thermal radiant energy is clearly observed, by the existence of spectral lines (Figures 2 and 3), to be absorbed into the bonds holding CO_2 molecules together. Temperature of air, as discussed above, is proportional to the average translational kinetic energy with which all the molecules making up air are moving. Conversion of bond energy in small concentrations of CO_2 to translational kinetic energy of all gas molecules has never been demonstrated and quantified in the laboratory. Since CO_2 makes up only 0.04% of all air molecules and CO_2 molecules absorb less than 16%

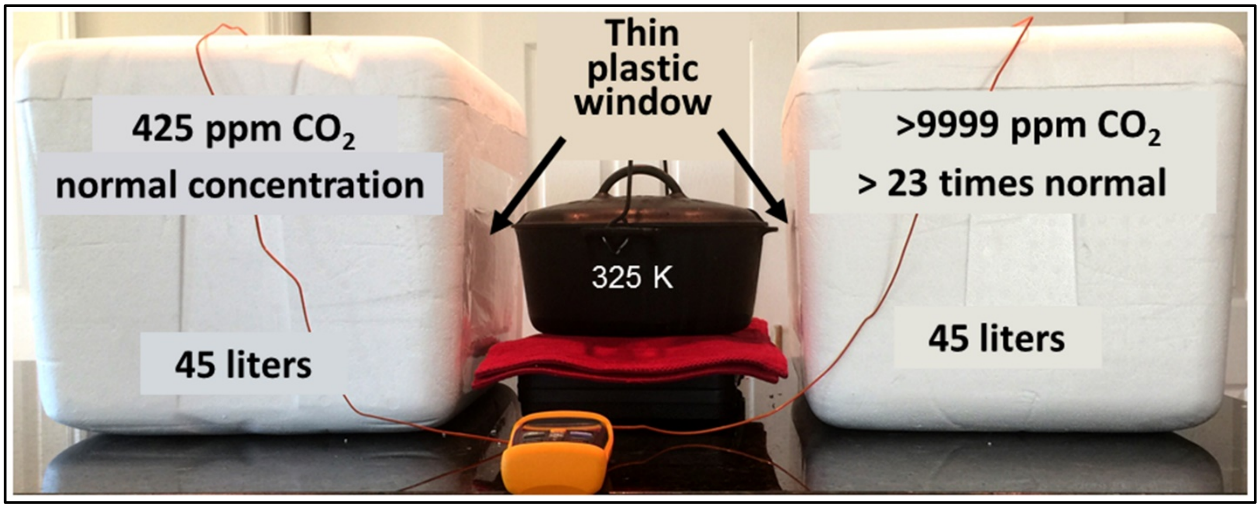

Figure 4. The Styrofoam box on the left contains normal air with 425 ppm CO_2. The box on the right contains more than 9999 ppm CO_2 measured at the end of the experiment. The cast-iron Dutch oven is full of water with the outside surface at 325 Kelvin. The red wires lead to thermistors inserted 2.5 cm below the inside of the top lid.

of the frequencies making up Earth's thermal radiation, even under the most favorable assumptions, the average kinetic energy of all air molecules can only be increased by less than 0.0064%, which is 0.18 K for a body like Earth at 288 K. Greenhouse gases simply do not absorb enough heat to have a significant effect on global temperatures.

Mechanism 1, direct heating of air: I performed an experiment, described in detail in the supplementary materials, comparing the temperature increase when two different volumes of air, each about 45 liters, contained within Styrofoam containers, were exposed to infrared radiation from a black pot of water at 325 K (Figure 4). One volume consisted of normal air containing 425 ppm CO_2. The second contained more than 9999 ppm CO_2, the upper limit of my CO_2 meter. This CO_2-rich air (red line, Figure 5a) warmed only 0.1 K more than normal air (black line), reaching its peak temperature 50 seconds sooner, and cooling approximately 400 seconds slower. The resolution of my digital thermometers is only 0.1 K. Thus, the thermal effect of having far more than 23 times normal amounts of CO_2 absorbing infrared radiation from a black body under these circumstances was barely detectable. This simple, inexpensive, and easily reproducible experiment shows that there is no evidence that a mere doubling of CO_2 concentrations could directly heat air even a small part of the 1.5 °C to 4.5 °C global warming that the IPCC (2013) concludes is highly likely.

One can wonder whether the 45-liter volume of air involved is large enough to approximate atmospheric conditions. Since warming is assumed to be caused by an increase in the concentration, the density of CO_2 molecules in well-mixed air, the temperature increase must be the same for any volume of air.

One can also wonder about the effects of the walls of the Styrofoam containers as they absorb and emit infrared radiation. That is why this experiment has been designed so that the boundary conditions of these two bodies of air are identical and why both systems are measured at the same time, heated by the same source. The only difference is in the concentration of CO_2. Increasing CO_2 concentration by a factor of more than 23 times is observed not to cause the system to absorb significantly more thermal energy as predicted by theory described above.

Mechanism 2, direct heating of air that slows the rate of heat loss from Earth: Even if air were directly heated by an increase in greenhouse-gas concentrations, the rate of heat loss from Earth's surface is observed to be determined primarily by convection caused by differences in density of warm air and cool air. Convection is driven by warm air rising and by warm air moving from the tropics to the poles. The widespread dominance of these motions is shown clearly by wind systems, weather systems, and ocean currents. We all know from practical experience that our bodies lose heat much faster standing in a breeze than standing with no wind.

The rate of heat loss is also influenced greatly by water-vapor concentrations and by precipitation. The lapse rate, the rate at which tropospheric temperature is observed to decrease with increasing altitude, is approximately 5 ^{o}C per kilometer for moist air, 9.8 ^{o}C for dry air, and averages closer to 6.5 ^{o}C. Water is the primary absorber of thermal energy in the atmosphere, as shown clearly in Figure 2, and moist air rising and condensing nearly doubles the rate of heat loss.

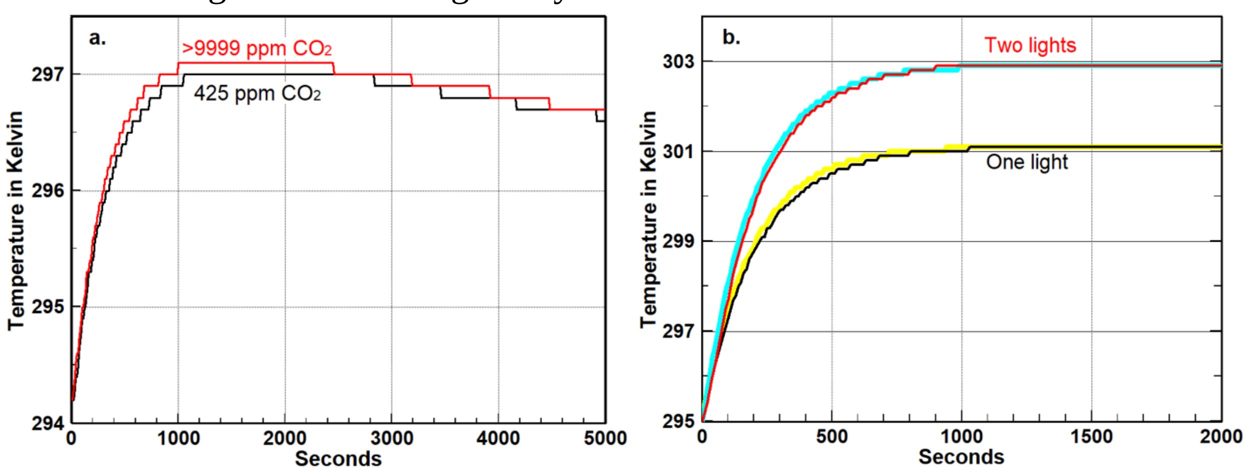

Figure 5a.) The volume of air containing >9999 ppm CO_2 (red line) warmed 0.1K more than a similar volume of normal air (black line) containing 425 ppm CO_2. b.) Temperature increases rapidly when beginning to warm a metal plate by radiation from a light, but decreases exponentially as it approaches the ultimate temperature.

The fundamental role of resonance: Thermal energy is the oscillation of all the bonds that hold the body together resulting in a body's temperature (Figure 1). The energy of oscillation (E) of a single frictionless atomic oscillator, a single degree of freedom of a single molecular bond, is defined by the Planck-Einstein relation as equal to the Planck constant (h) times the frequency of oscillation (ν, the Greek letter nu) so that $E=h\nu$. Since frequency of oscillation (ν) is observed to be a broad continuum of frequencies (Figures 1 and S4), energy (E) of a large ensemble of such atomic oscillators is observed to be a broad continuum of energies of oscillation ($E=h\nu$) explained in more detail by Ward (2017). Thus thermal energy is clearly not quantized.

Oscillations of atomic and molecular bonds, often modeled as Morse potential energy functions, are frictionless. While the frequency and thus energy of oscillation may be increased by increasing temperature and decreased by decreasing temperature, the only way amplitudes of oscillation, intensities of oscillation, can be shared between oscillators making up bodies of matter is via resonance. This is an extremely important observation because it accurately describes how thermal energy is observed to flow physically within matter and via radiation.

Resonance is where two discrete oscillators, oscillating at the same frequency, "share" amplitudes of oscillation. In matter, this sharing is the basis for conduction, facilitated by physical contact. In air and space, however, this sharing is done between pieces of matter via line of sight through an electromagnetic field. The oscillator with the highest amplitude of oscillation "gives up" half the difference in amplitude of oscillation to the oscillator with the lower amplitude of oscillation, causing both oscillators to end up with the same amplitude of oscillation. This averaging, due to the way resonance works, results in more energy being transferred when the difference in amplitude of oscillation, which is related to the difference in temperature (Figure 1), is large and very little energy being transferred when the difference in amplitude of oscillation, the difference in temperature, is small.

This averaging of amplitudes of oscillation at the molecular level in bodies of matter is well observed at the macroscopic level as an averaging of temperature of matter. If the physical properties of two bodies of matter are identical except for temperature and they are joined thermally, the resulting temperature at thermal equilibrium will be the average of the two initial temperatures. This averaging can be observed experimentally by shining a bright light on a small piece of black metal in experiment 2 described in the supplementary materials. Temperature rises quickly at first and then much more slowly as the metal approaches its warmest temperature (Figure 5b). The black line shows temperature measured every 10 seconds. The yellow line shows the temperature every ten seconds calculated as an increase of five percent of the difference between the previous temperature and the ultimate temperature. Both curves are essentially identical.

Note that the flux of thermal energy, the rate of change of temperature, starts high and decreases exponentially with time, a stepwise averaging explained clearly by resonance. Having two identical light sources doubles the flux of thermal energy available while not changing the simultaneous loss of thermal energy, leading to an increase, but not a doubling of the ultimate temperature. If the metal plate were not simultaneously losing energy by re-radiation, by convection, and by conduction, its temperature would approach the temperature of the light source (3000 K).

Resonance plays the primary role in absorption of infrared radiation by greenhouse gas molecules. The spectral lines discussed above (Figures 2 and 3) are the resonant frequencies of the molecule. We think of a specific degree of freedom of a specific bond holding a molecule of gas together as resonating with an electromagnetic field, extracting a spectral line of energy. A more precise way to explain the physics at the molecular level appears to be that a specific degree of freedom of a specific bond holding the absorbing molecule together is resonating with a specific oscillator on the surface of the radiating matter via line of sight. Energy only flows from the oscillator with higher amplitude of oscillation to the oscillator with lower amplitude of oscillation at the same frequency, which, as shown in Figure 1, means from higher temperature to lower temperature, a fact so widely observed that it is one form of the second law of thermodynamics.

Amplitude of oscillation in radiation is well observed to decrease inversely proportional to the square of the distance travelled. This can be understood in terms of resonance to result from the reality that rays of light diverge, so that the density of molecular bonds on the surface of the radiating body within line of sight from the resonating bonds on the surface of the absorbing body decreases with the square of distance traveled, meaning fewer bonds can resonate simultaneously, so that the amplitude absorbed must be shared by conduction among more bonds on the surface of the absorbing body.

Mechanism 3, re-radiation of absorbed energy that slows the rate of heat loss from Earth: Central to greenhouse effect defined above is the widespread assumption that terrestrial infrared radiation absorbed by gas molecules of CO_2 is re-radiated in all directions. The only frequencies that can be re-radiated, however, are those absorbed, which make up <20% of terrestrial radiation (vertical black bars in Figure 1). Furthermore, at temperatures prevalent in Earth’s atmosphere, molecular electronic transitions are not involved. An electronic transition is where an electron is excited into a higher energy level by absorbing radiant energy and the molecule is thought to radiate this energy as the electron returns to its lower energy level. Thus, a molecule of CO_2 gas in Earth's troposphere is unlikely to spontaneously re-emit radiation.

Given the primary role of resonance, a molecule of CO_2 can only lose bond energy to another oscillator at the same frequency with a lower amplitude of oscillation, which would not be in the direction of Earth because the atmosphere is cooler than Earth. Furthermore, with only one molecule of CO_2 amidst 2500 molecules of other gases, such transfer is likely to be rare. If thermal energy is radiated away, it must be replaced by absorption for radiation to continue. This is how the photosphere of Sun and the stratopause of Earth can be radiative surfaces because the heat radiated is immediately replaced from below by rising heat.

Water vapor, alternatively, absorbs a very broad range of frequencies of oscillation (Figure 2), makes up, on average, 0.1% of atmospheric gases, and reaches high concentrations in clouds. A water molecule on top of a cloud can resonate with a molecule on the photosphere of Sun, warming the cloud. A water molecule near the base of the cloud can resonate with a molecule on Earth's surface thereby slowing the rate of heat loss from that particular point on Earth. Pointing an infrared thermometer gun into the blue sky, it might read 1 ^{o}C, while pointed at a cloud, it might read 18 ^{o}C (NASA, 2017), showing that a cloud, warmed by Sun, is a radiative surface whose molecules can resonate, can share amplitude with molecules on Earth and on Sun. Radiation downwelling from the atmosphere is measured. The Planck's law distribution of this radiation needs to be measured in detail to determine the temperature and location of the source.

Water vapor and precipitation play major roles determining local and regional temperatures on Earth and a warmer climate is likely to evaporate more water vapor into the atmosphere. Long-term changes in average global concentrations of water vapor, however, have not been proposed as a cause for long-term changes in global mean surface temperatures.

Mechanism 4 , re-radiation of absorbed energy back to Earth where it is absorbed and causes warming of Earth: Fourier (1822) proposed the concept of global energy balance, which has been developed in detail by Kiehl and Trenberth (1997), Trenberth and Fasullo (2012) (Figure 6) and Wild et al. (2013), concluding that flux of downwelling radiation from greenhouse gases in the atmosphere (333 Wm^{-2}) is more than twice the incoming flux of solar radiation absorbed by Earth's surface (161 Wm^{-2}). This does not make physical sense. Radiative flux is the amount of thermal energy that flows per second—the higher the flux, the warmer you feel. We all know by personal experience that radiation from Sun feels much hotter than radiation from clouds in the lower atmosphere, or radiation from the atmosphere when Sun is not in view day or night. Furthermore, assuming such downwelling radiation requires that heat flows from a colder atmosphere to a warmer Earth, breaking the second law of thermodynamics. In addition, radiation from a colder body does not contain high enough amplitudes of oscillation at all frequencies of oscillation to warm a warmer body (Figure 1).

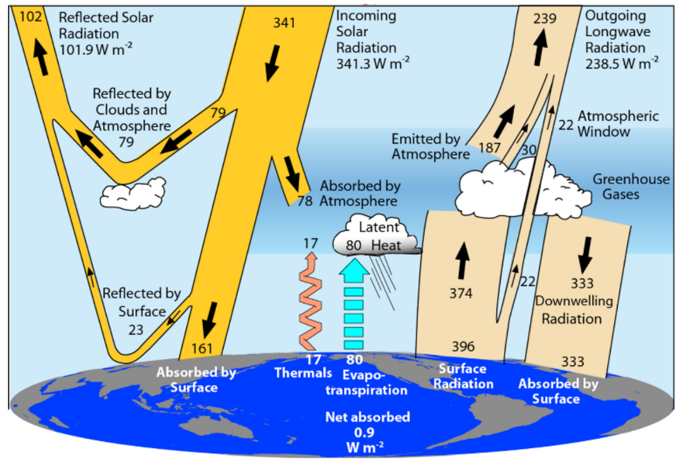

Figure 6. The global annual mean Earth's energy budget for 2000 to 2005 suggesting that observed global warming is the result of the net radiant energy absorbed by Earth (0.9 W m^{-2}) (Trenberth and Fasullo, 2012).

The problem here stems from the way we currently think about thermal energy, heat, radiation, and radiant flux based on Maxwell's equations for electromagnetic waves. Energy of waves is the energy needed to deform the medium through which the waves are traveling. The more energy, the greater the amplitude of the waves. Thermal energy, however, is frequency of oscillation, $E=h\nu$. Frequency of oscillation is the actual energy and this energy is observed to increase with frequency (Figures 1 and S4). The level of radiant energy is not a function of wave amplitude as calculated using Maxwell's equations, it is not a function of the numbers of photons as explained in the supplementary materials, and it is not a function of the amount of energy you have. The level of radiant energy is a function of frequency only ($E=h\nu$), which is a function of the temperature of the radiating body (Figure 1).

If $E=h\nu$, then radiative forcing, a concept integral to greenhouse-warming theory (Myhre et al., 2013), is not a single number of watts per square meter, as currently calculated in Figure 6, but is a broad continuum of watts per square meter where higher frequencies have a much greater effect on the flow of heat than lower frequencies. Flux of thermal energy per second per square meter is different for every frequency. Net flux, therefore, must be a broad continuum where flux is much higher for higher frequencies, which says more thermal energy flows from hotter bodies—something that is well observed. Because heat flows by resonance, flux is also higher for larger differences in temperatures, which means larger differences in amplitudes of oscillation (Figure 1) and lower for smaller differences, something not taken into account by current calculations.

The other fundamental problem with global energy balance calculations (Figure 6), is that they do not include the major heating of the stratosphere by solar energy that occurs every day. Solar ultraviolet-C radiation has high enough energy to dissociate oxygen and many other chemical species. Upon dissociation, the molecular pieces fly apart at high velocity, turning bond energy directly into translational kinetic energy, which is directly proportional to the temperature of air. The stratopause is maintained daily at temperatures more than 50 K warmer than the tropopause, providing an "electric blanket" around Earth, keeping Earth warm. Electric in the sense that the heat comes from a distant source, Sun, not from the body under the blanket, Earth.

Mechanism 5, climate feedbacks: Numerous feedbacks thought to amplify greenhouse warming have been proposed including snow and ice albedo, water vapor and lapse rate, clouds, aerosols, carbon sinks, and wetland methane emissions (IPCC, 2013). It is not clear that greenhouse warming is significant as described above, so the importance of these feedbacks must be reevaluated recognizing that thermal energy is a function of frequency of oscillation of the bonds holding matter together. Ultraviolet radiation, for example, has enough energy to sublimate snow, explaining why snow banks on the south side of my house at 6200 feet disappear on sunny days without evidence of water runoff.

Discussion: Global warming is a problem, but there are now numerous observations and some simple experiments summarized in this paper suggesting that a doubling of greenhouse-gas emissions physically cannot cause observed global warming. Greenhouse-warming theory appears to be mistaken.

The fundamental problem is that, based on wave theory and quantum theory, we think of thermal energy as an amount or flux in watts per square meter without ever defining what thermal energy physically is. We assume that all radiation is created equal so all that matters is the flux, the amount of generic radiation that exists. We calculate that a hotter body similarly radiates more watts than a cooler body, that a cold body must absorb watts to become warmer, and that the more watts it absorbs, the hotter the body will become. These calculations of energy flux have been fundamental to physics and engineering for more than a century and they have been refined to work quite well when all types of radiation can be considered equal.

In climate, however, all radiation cannot be considered equal. Solar radiation contains much higher frequencies, higher energies, than terrestrial radiation. The highest frequency, highest energy, solar ultraviolet radiation is absorbed in the atmosphere, forming and heating the thermosphere, ionosphere, stratosphere, and ozone layer. If Earth did not have an atmosphere, very high energy solar ultraviolet-C radiation would raise surface temperatures from 288 K to as much as 396 K, like those on the moon, boiling off the oceans. The highest energy solar radiation to reach the lower stratosphere is ultraviolet-B, which is normally absorbed by the ozone layer. When the ozone layer is depleted, more ultraviolet-B is observed to reach and warm Earth. Ultraviolet-B is nearly 50 times more energetic than infrared radiation absorbed most strongly by CO_2 and is, therefore, 50 times "hotter", meaning that ultraviolet-B radiation has the potential, if the amplitude of oscillation is high enough, to warm the absorbing body to 50 times the temperature of a body absorbing infrared radiation. This is why changes in the amount of ultraviolet-B reaching Earth have the primary effect on changes in Earth's temperature.

As explained in this paper, observations and experiments show that:

1. thermal energy in matter is physically the oscillation of all the degrees of freedom of all the bonds that hold matter together,
2. these oscillations on the surface of matter induce electromagnetic radiation that enables propagation of thermal energy over short to galactic distances via resonance,
3. the distribution of frequencies and amplitudes of these oscillations within matter and within radiation is determined by the temperature of the radiating body as shown by Planck's law,
4. thermal energy ($E=h\nu$) is frequency of oscillation (ν) scaled to specific units by the Planck constant (h),
5. the distribution of frequencies and amplitudes of oscillation determine the thermal effects of absorbing radiation, and
6. the amount of thermal energy determines the rate of warming, but the distribution of frequencies and amplitudes of oscillation determine the temperature.

The IPCC was founded in 1988 to develop consensus behind greenhouse-warming theory to convince politicians to take action. The IPCC has successfully involved thousands of top atmospheric scientists who, through group think and writing tens of thousands of pages of very thoughtful reports, have developed a "scientific consensus" that became pervasive enough to enable the Paris Agreement, on 12 December 2015. There is now strong urging to move promptly to safeguard our climate (Figueres et al., 2017). While efforts to increase non-fossil-fuel energy resources will have long-term value, what if reducing greenhouse emissions at great cost has no significant effect on global warming? The primary problems are that science is not done by consensus and the science of climate change is evolving.

Observations of global warming since 1950 and throughout the history of Earth are explained much more clearly and in much greater detail by depletion of the ozone layer caused by manufactured CFC gases and by chlorine and bromine emitted from active volcanoes as explained in detail by Ward (2016a), (Ward, 2016b), and at WhyClimateChanges.com. A depleted ozone layer is clearly observed to allow more ultraviolet-B solar radiation to reach Earth, cooling the ozone layer and warming Earth, especially the oceans. The Montreal Protocol led to a cutback in manufacturing of CFC gases by 1993, stopping the increase in ozone depletion by 1995, but ozone remains depleted, oceans continue to warm, glaciers continue to melt, and sea level is rising at a 50% higher rate in 2014 than in 1993 (Chen et al., 2017). Unfortunately, the decline in ozone depletion has been extremely slow because CFCs are chemically very stable, because there is a substantial black market in CFCs in developing countries (UNEP, 2007), because there are still many "essential" uses of small amounts of CFCs for critical processes such as inhalers, because the Montreal Protocol does not regulate certain ozone depleting substances such as N_2O, and because there has been major growth in the use of short-term ozone depleting gases not regulated by the Montreal Protocol such as dichloromethane (Hossaini et al., 2017).

We still have much to learn about ozone depletion (Anderson et al., 2017). Whether we agree that greenhouse gases are important or not, we must move promptly to stop the use of ozone-depleting substances, to improve our understanding of the chemistry of ozone depletion, and to reduce substantially current levels of ozone depletion. Ozone remains depleted largely caused by humans, the world continues to warm, and we do not have any proven, practical ways to cool the world back to pre-1969 mean global temperatures. On the positive side, however, if warming is not caused primarily by greenhouse gases, then the major warming predicted by current climate models will not happen and has not happened since 1998.

Supplementary Materials

Key issues in the development of greenhouse-warming theory
Experiment 1, measuring the direct heating of air
Experiment 2, warming a metal plate with radiation
The electromagnetic spectrum
More on resonance
Problems with traditional calculations of thermal energy
The Planck constant

Why electromagnetic radiation does not appear to propagate as waves or as photons

Key issues in the development of greenhouse-warming theory: Six scientists led the early development of greenhouse-warming theory. Joseph Fourier (1822) noted a clear distinction between solar visible heat and the much more "*feeble*" invisible infrared radiation from Earth. He noted that sunshine "*would raise [Earth's] mean temperature more and more, if the heat acquired were not exactly balanced by that which escapes in rays from all points of the surface and expands through the sky.*"

Second, John Tyndall (1859) demonstrated in the laboratory that "*the atmosphere admits of the entrance of the solar heat, but checks its exit; and the result is a tendency to accumulate at the surface of the planet.*" Tyndall (1861) concluded that "*elementary gases hydrogen, oxygen, nitrogen, and the mixture atmospheric air, possess absorptive and radiative powers beyond comparison less than those of the compound gases.*" Compound gases, containing three or more atoms per molecule and making up only 1 out of every 2500 molecules in Earth's dry atmosphere, ultimately became known as greenhouse gases, the most important of which are water (0.4% on average), carbon dioxide (400 ppm), methane (1800 ppb), nitrous oxide (328 ppb) and ozone (337 ppb) (Blasing, 2016).

Third, James Maxwell (1865) formulated a set of partial differential equations assuming that electromagnetic radiation travels through air and space as transverse waves. Maxwell's assumption has since dominated observations and interpretations of radiation, including estimates of radiant energy and thermal flux, even though no one can explain physically how waves, which deform the bonds holding matter together, can propagate through space, where there is no matter and there are no bonds.

Fourth, Samuel Langley (1889) carefully measured radiation coming from the moon in order to determine the frequencies of infrared radiation absorbed in the atmosphere.

Fifth, Knut Ångström (1892) measured infrared absorption bands for water, carbon dioxide, methane, and several other gases.

Sixth, Svante Arrhenius (1896), based on Langley's and Angstrom's data, and a new law for radiant emission based on Maxwell's equations (Stefan, 1879), calculated that doubling the concentration of carbon dioxide in the atmosphere should warm Earth 4.95 ^{o}C in the tropics to 6.05 ^{o}C at 60 to 70 ^{o}N, concluding that "*if the quantity of carbonic acid [CO_2] increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression.*" Note that calculating temperature to three significant figures is certainly not warranted by the data. Arrhenius provides the conceptual foundation for greenhouse-warming theory and the basic mathematical approach that evolved eventually into modern climate models. As Kutzbach (1996), a paleoclimate modeler, explains, Arrhenius' estimates "*happen to be very close to modern-day estimates even though Arrhenius ignored the possible effects of changes of horizontal advection and cloud cover and used a radiative transfer model that was much less detailed than present-day models.*"

Crawford (1997), putting Arrhenius' model of the greenhouse-warming theory in context, concludes: "*Arrhenius' final results are impressive both as an innovative exercise in model-building and as a first approximation of the influence of CO_2 on climate. This should not make one forget, however, that they hardly rested on solid empirical ground.*" Arrhenius admits, for wavelengths greater than 9.5 micrometers (dotted blue line in Figure 2), that "*we possess no direct observations of the emission or absorption of the two gases,*" water and CO_2, yet the atmospheric window of little absorption is between 8 and 12 micrometers, the main absorption band for CO_2 is around 14.9 micrometers, and water strongly absorbs radiation with wavelengths greater than 15 micrometers (Figure 2). Arrhenius made many thoughtful estimates and simplifying assumptions, but few were grounded in reliable data.

Arrhenius founded the Stockholm Physics Society in 1891, hosting lively fortnightly discussions of science. Several scientists discussed CO_2 in 1892 and the origin of ice ages in 1893. In December 1894, Arrhenius heard a lecture elsewhere that caused him to wonder whether decreasing atmospheric concentrations of carbon dioxide by a factor of two could possibly explain ice ages.

More than a century later, Lüthi et al. (2008) showed that concentrations of CO_2 increased only by a factor of approximately 1.4 from glacial to interglacial periods during the nine ice-age cycles over the past 800,000 years. Such changes in atmospheric CO_2 concentrations could be explained simply by decreased solubility in a warming ocean (Zeebe and Wolf-Gladrow, 2001). Concentrations of CO_2 appear in most but not all detailed studies of these cycles to increase within 400 years after ocean temperatures began rising (e.g. Pedro et al., 2012; Siegenthaler et al., 2005). Thus, the data suggest that increases in atmospheric concentrations of CO_2 could be the result of a warming ocean, not the cause, of that warming.

Experiments done by Ångström (1900), who regularly attended the Stockholm Physics Society, raised serious questions about Arrhenius' conclusions. Arrhenius' knew from discussions with his friend Arvid Högbom (1895), a geologist studying the carbon cycle, that global temperatures appear to decrease about 5 ^{o}C during ice ages. Therefore, Arrhenius was trying to determine whether plausible decreases in

CO_2 could cause this amount of cooling. His calculations were thoughtful back-of-the-envelope estimates at best.

Most scientists at the time were not convinced (Fleming, 1998; Fleming, 2002). Greenhouse-warming theory was largely ignored until resurrected by Guy Callendar (1938), a British steam engineer and amateur meteorologist. No physicist since Ångström (1900) has published work trying to determine by how much the temperature of air would be increased when greenhouse gases absorb terrestrial infrared radiation. Callendar shrugged off Ångström's work in two short sentences among his boxes of detailed notes saying Ångström (1900) "*tried the effect on the observed sky radiation of putting a tube containing 50 cms of CO_2 over his instruments. Could not obtain any measureable effect, as would be expected with the apparatus used*" (Fleming and Fleming, 2007). This short note documents a fundamental breakdown in the development of the physics of greenhouse-warming theory.

From 1884 to 1891, Arrhenius worked in several leading chemistry laboratories in Europe, gaining extensive understanding of experimental methods and ultimately earning the 1903 Nobel Prize in Chemistry for his electrolytic theory of dissociation. On page three of his 1896 climate paper, Arrhenius states: "*In order to get an idea of how strongly the radiation of the earth … is absorbed by quantities of water-vapor or carbonic acid [CO_2], … one should, strictly speaking, arrange experiments on the absorption of heat from a body at 15° by means of appropriate quantities of both gases. But such experiments have not been made as yet, and, as they would require very expensive apparatus beyond that at my disposal, I have not been in a position to execute them.*" While absorption of radiation by gases has since been studied in considerable detail, the effects of this absorption on the temperature of air has never been determined experimentally. Test of theory by experiment is fundamental to the scientific method. How could Arrhenius' back-of-the-envelope estimates have become so important today scientifically, economically, and politically without such a definitive experiment, an experiment that could have been rather inexpensive as shown below?

Experiment 1, measuring the direct heating of air: I first took two one gallon (3.8 liter), wide mouth, food-grade plastic jars, inserting a thermistor 2 cm through a small hole in the plastic top of each jar. I filled one jar with normal air containing 425 ppm CO_2 as measured with an Amprobe CO_2-100 carbon dioxide meter and filled the other with CO_2 from a Genuine Innovations G2153 16 gram CO_2 cartridge measuring in the jar, at the end of the experiment, >9999 ppm CO_2, the upper limit of the meter. I put both jars next to a black, cast iron, Dutch oven with lid, filled with water and heated to 312 K, measured using an Etekcity Lasergrip 1080 Digital Laser Infrared Thermometer. Both thermistors were monitored using

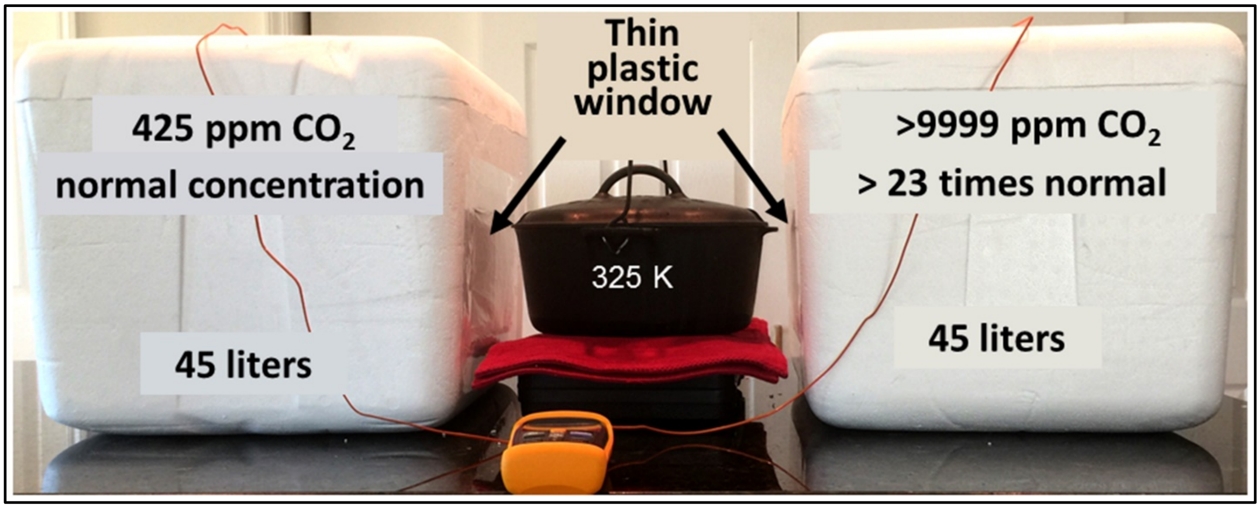

Figure S1. The Styrofoam box on the left contains normal air with 425 ppm CO_2. The box on the right contains more than 9999 ppm CO_2 measured at the end of the experiment. The cast-iron Dutch oven is full of water with the outside surface at 325 Kelvin. The red wires lead to thermistors inserted 2.5 cm below inside of the top lid.

a Fluke 54-2 Dual Input Digital Thermometer with a sensitivity of 0.1 K, logging one sample every ten seconds, with data downloaded to FlukeView Forms software.

No difference in temperatures in the two jars was noted during 90 minutes of recording. I had chosen plastic because infrared does not penetrate glass. I then found that putting the infrared thermometer inside one of these plastic jars and pointing the beam to a surface outside of the jar, the meter read 23.2°C instead of 33.7°C measured without the jar. Clearly some infrared was not penetrating the plastic jar. Therefore, I took two thin plastic bags used in grocery stores to put vegetables in, checking that the infrared thermometer read the same value through one layer of bag and without the bag. I hung these bags on the thermistor cables in a black enclosure meant to reduce convection surrounding the bags. Still no difference in temperatures measured, but heat was clearly being lost rapidly through the bag surfaces.

I then took two Styrofoam boxes commonly used to ship frozen meats with dry ice (solid CO_2) that each contained about 45 liters of air (inside dimensions 47.6 by 33.7 by 27.9 cm). I cut a hole in one side of each box 27.6 cm wide by 12.7 cm high to match the dimensions of the Dutch oven and glued and taped one layer thickness of a grocery plastic bag on the outside of each hole to prevent exchange of heat by convection and to keep the CO_2 within the box. I poked a thermistor through the center of the top of each box, protruding inside 2.5 cm below the Styrofoam with the wire taped on the outside. Placing the boxes as shown in Figure S1 with the Dutch oven at 325 K, the box on the right, containing >9999 ppm CO_2

measured at the end of the experiment, warmed 0.1 K more than the box on the left containing 425 ppm CO_2, reached peak temperature at 1000 seconds, 50 seconds faster, and cooled approximately 400 seconds slower (Figure S2). Thus, there was a barely detectable thermal effect resulting from having far more than 23 times as much CO_2 absorbing infrared radiation from a close-by black body under these circumstances. I tried this experiment 4 times with essentially identical results. Clearly there is no evidence that a mere doubling of CO_2 concentration can directly cause degrees of warming of air as anticipated by the IPCC (2013).

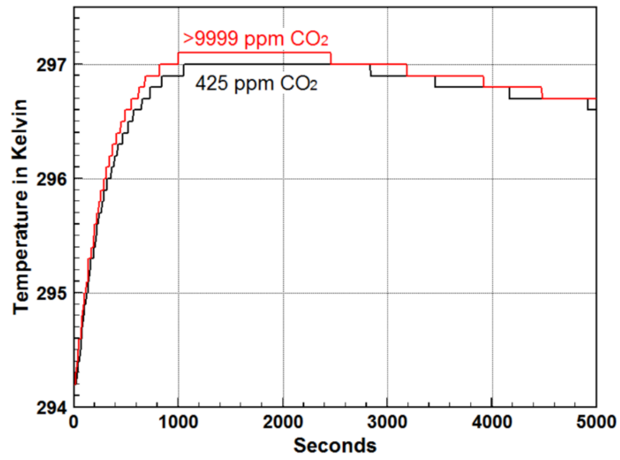

Figure S2. The box on the right containing >9999 ppm CO_2 warmed 0.1K more than the box on the left containing 425 ppm CO_2, reached peak temperature 50 seconds faster, and cooled approximately 400 seconds slower.

This experiment is deliberately designed to be symmetrical so that the boundary conditions surrounding each body of air are identical.

When a CO_2 cartridge is punctured, the gas and the capsule cool rapidly due to the release of pressure. Therefore, I did not start the experiment until the normal air and CO-rich air had reached the same temperature.

Experiment 2, warming a metal plate with radiation: I did nine 30-minute experiments illuminating a 30 by 46 cm, 16-gauge piece of sheet metal, painted flat black, suspended by two very fine wires, with one to four 50W MR16 ESX picture lights placed 90 cm away. The thermistor was bolted to the center of the back side of the plate with a 2-56 bolt and washer. I did an additional twelve 30-minute experiments illuminating a 5-cm-square, 16-gauge piece of sheet metal, painted flat black, held up by the thermistor wire similarly bolted to the center of the back side of the

Figure S3. Four picture lights shining in a 2-inch square black metal plate inside of a vacuum jar.

plate (Figure S3). The first of these latter experiments was with plate mounted on the vacuum base, the second with the glass vacuum dome (7.25 inch inside diameter) in place, and the rest with a vacuum of -24 inches of mercury to minimize transfer of heat by convection. All experiments showed warming similar to that plotted in Figure 5b. The 5-cm plate became 1.5 K warmer inside the vacuum dome, with or without a vacuum, rather than in open air. This is interesting given that the glass vacuum dome would inhibit the lower frequency infrared radiation from entering or leaving the dome. Each light added increased the maximum temperature of the plate approximately 2 K. The purpose of these experiments was simply to examine the logarithmic warming caused by radiation and the effects of the rate of warming and the maximum temperature reached.

The electromagnetic spectrum is a continuum of frequencies of oscillation extending from low frequencies used in radio communication to very high frequencies of gamma rays (Figure S4). Since Maxwell (1865), it has been traditional to think of electromagnetic radiation in terms of waves, calculating a wavelength, which is equal to the velocity of light divided by wave frequency. The concept of wavelength is useful in estimating the length scale of the physical oscillators involved shown at the top of Figure S4. For example, cone cells in the human retina have lengths on the order of 0.5 micrometers making them resonate

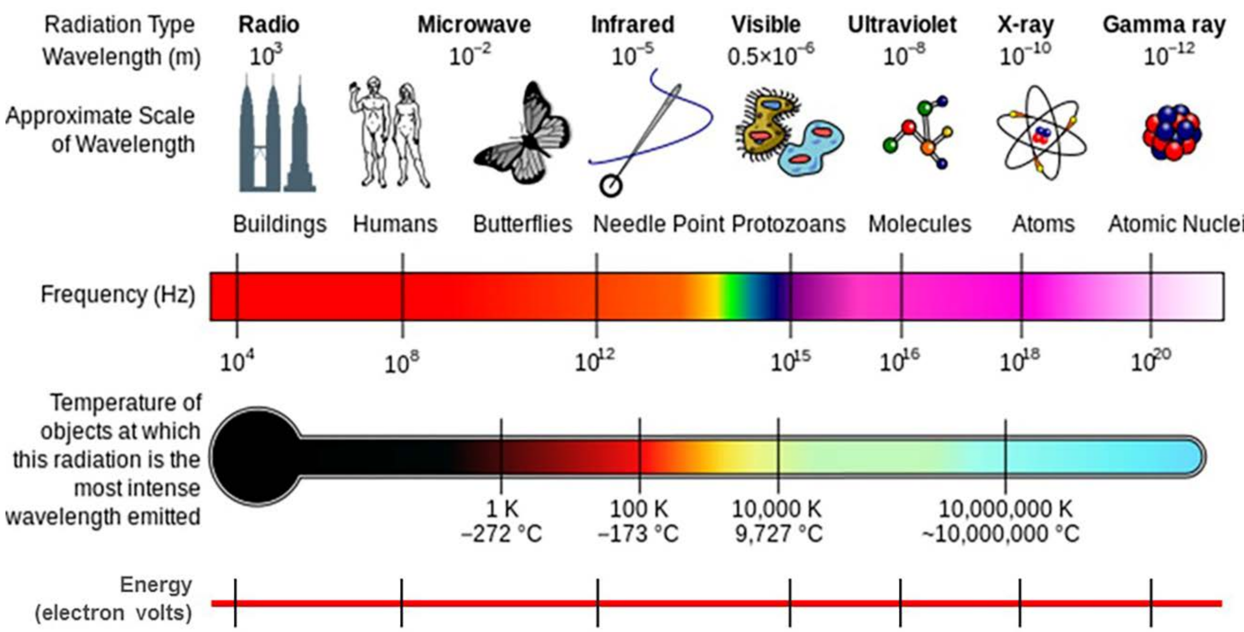

Figure S4. The electromagnetic spectrum extends over at least 14 orders of magnitude of frequency. Energy is equal to the frequency times the Planck constant. The temperature of objects for which the radiation at a given frequency is the most intense similarly increases with frequency and energy.
(Based on commons.wikimedia.org/wiki/File:EM_Spectrum_Properties_edit.svg)

at frequencies of oscillation in the range of 430 to 770 terahertz, the minimum and maximum frequencies of visible light. Gamma rays, the highest frequency, highest energy electromagnetic radiation, can only be formed by oscillations of the tiny bonds within an atomic nucleus.

More on resonance: Resonance is the physical basis for what Einstein called "spooky action at a distance" (Born et al., 1971, p. 155), where something over there influences something over here, but there is no visible connection between them. Resonance is also the physical phenomenon that the mathematical theory of quantum entanglement seeks to explain even though quantum entanglement has taken on a rich number of mathematical properties.

Resonance plays the major role not only in temperature and the flow of heat, but also in sight and sound. Visible light is visible precisely because the cone cells in our eyes have sizes that resonate at visible frequencies. The cilia in our ears resonate with frequencies of sounds. A radio receiver tuned to resonate at the frequency of a specific radio transmitter, extracts that small signal from the frequency continuum.

Problems with traditional calculations of thermal energy: Planck's law (Figure 1) was formulated empirically to explain measurements in the laboratory collected during the 1880s and 1890s by separating the radiation of interest into a rainbow spectrum, using a glass prism for visible and ultraviolet frequencies and a halite prism for infrared frequencies that are not energetic enough to penetrate glass. The scientists then placed a temperature sensor within each narrow spectral band, measuring the increase in temperature of a small piece of mass within the sensor as volts. They were, therefore, measuring the thermal effect of this narrow band of radiation on a small piece of matter. Based on Maxwell's wave theory for radiation, they thought they were measuring the amount of energy required to cause this thermal effect in units including watts per square meter on the y-axis as a function of frequency of oscillation in cycles per second on the x-axis (Figure 1).

Yet energy (E) at the molecular level in both matter and radiation is equal to the Planck constant (h) times frequency of oscillation (ν): $E=h\nu$. Thus, energy should be plotted on an alternative x-axis, the upper x-axis in Figure 1, not on the y-axis. What they were measuring in volts and thinking of as flux in watts was actually a proxy for amplitude of oscillation along a continuum. The fundamental physical properties of frictionless atomic oscillators and the electromagnetic radiation they induce are frequency of oscillation and amplitude of oscillation. Amplitude of oscillation needs to be calibrated experimentally in the laboratory. That is why no units for amplitude of oscillation are shown on the logarithmic y-axis in Figure 1, only orders of magnitude. As shown in Figure 1, macroscopic temperature is determined by a broad continuum of frequencies of oscillation at the molecular level, each with a specific amplitude of oscillation calculated using Planck's law. This continuum of energy at the molecular level is best represented at the macroscopic level by a single number for temperature, the result of all these molecular level energies after the ensemble of oscillations reaches thermal equilibrium.

This same confusion is contained in the Stefan-Boltzmann law (Stefan, 1879), where the total energy (j^*) radiated per unit surface area of a black body across all wavelengths per unit time equals a constant (σ) times temperature to the fourth power, $j^*=\sigma T^4$, which can be derived by integrating Planck's law. Planck's law and the Stefan-Boltzmann law do not allow for the fact that energy is a function of a continuum of frequencies, and is not a function of bandwidth as currently assumed.

The Planck constant: If $E=h\nu$, then $h=E/\nu$, showing that the Planck constant (h) is simply the energy contained in one cycle per second. The Planck constant can be estimated easily in a high school physics laboratory using four different colored LEDs with four different frequencies of oscillation, which by $E=h\nu$ are four different levels of energy (Rute and Sérgio, 2014). The Planck constant ($h=E/\nu$) has units of energy per cycle per second but is often mistakenly specified with units of energy seconds because the unit cycle is commonly thought of as not important. Cycle, however, is very important because it specifies that we are talking about cyclic kinetic energy as opposed to translational kinetic energy.

Why electromagnetic radiation does not appear to propagate as waves or as photons: For 2500 years, leading natural philosophers and scientists have debated whether light, something we cannot see until it interacts with matter, travels through air and space as waves or as particles, things we can visualize. Doesn't it seem illogical to describe something we cannot see in terms of things we can visualize?

Light, electromagnetic radiation, is observed to contain a broad spectrum of frequencies (Figures 1 and S4) that we cannot see until light interacts with matter such as a prism or water droplets causing a rainbow. Today we are familiar with radio stations transmitting radiation at specific frequencies of oscillation, and a radio receiver that can be tuned to receive just the frequency of the desired station. These devices, however, became widespread only in the past century after physicists thought they understood what light is. While many physicists have concluded that frequencies and amplitudes of oscillations on the surface of the radiating matter generate the electromagnetic field, I have been unable to find in the literature any suggestion that light might simply travel as a continuum of frequencies in air and space, by line of sight, via the electromagnetic field that they generated and continue to generate as long as they are oscillating. Yet that is what appears to be happening.

Fresnel (1818) noticed that light could be polarized, concluding that light must therefore travel as transverse waves. He understood, however, that transverse waves can only propagate in solid matter, where the bonds holding the matter together provide the restoring forces that allow the waves to propagate. He therefore proposed that there must be some form of "luminiferous aether" in space that somehow provides those restoring forces.

Faraday (1849) introduced the concept of an electromagnetic field in air and space consisting of coupled transverse electric and magnetic waves vibrating in mutually perpendicular planes. An appropriate sensor placed within an invisible field records a value for each point in space and time.

Maxwell (1865) formulated a set of partial differential equations showing that electric and magnetic fields in space can satisfy wave equations when thinking of EMR as transverse waves traveling at some velocity. He showed that this velocity was equal to one divided by the square root of the product of two constants: the vacuum permittivity (the resistance to forming an electric field) times the magnetic permeability (the ability to form a magnetic field) (Maxwell, 1873). Thus, velocity of light appears to be proportional to the maximum rate at which an electric field can induce a magnetic field, which in turn can induce an electric field, ad infinitum. This very short increment in time would affect how fast frequency of oscillation would appear to travel via resonance in an electromagnetic field.

For decades, many physicists sought to discover what Fresnel's luminiferous aether was or to prove that it could not exist. An experiment by Michelson and Morley (1887) convinced most physicists that an aether does not exist and therefore waves cannot propagate through space. To this day, many physicists think there must be something different about electromagnetic waves that allows them to travel in space, but no one can explain the physical process in a physically intuitive way.

We observe that the physical properties of electromagnetic radiation (light) are distinctly different from the physical properties of mechanical waves in matter. Mechanical waves have frequencies defined as their velocity divided by their wavelength. The higher the frequencies, the more rapidly the waves are attenuated with distance. Frequencies of oscillation in light are a trillion times higher than frequencies for mechanical waves. They do not interact in any way and they are not attenuated with distance, even over galactic distances.

Electromagnetic radiation does exhibit wavelike properties such as reflection, diffraction, and interference when in the immediate vicinity of matter, but these effects appear to be caused by the bonds holding matter together. What is observed to be traveling physically in air and space, however, is simply a continuum of frequencies of oscillation (Figures 1 and S4).

Einstein (1905) introduced the concept of “light quanta”, a quantum of energy that ultimately became known as a photon (Lewis, 1926). Today, most physicists think of electromagnetic radiation as wave-particle duality, meaning sometimes it is more convenient to use wave equations and sometimes it is more convenient to use particle equations. As a basic point of logic, if something behaves sort of like waves and sort of like particles, then it is equal to neither.

For $E=h\nu$, if frequency (ν) is a continuum, and if h is a constant, then energy of oscillation (E) must be a continuum—not made up of discrete photons. There are many logical problems trying to describe a continuum as discrete photons. Is there a different photon for every decimal place of every frequency? How does a photon interact with a gas molecule? Does it collide with the gas molecule? If so, what happens if it glances off the molecule? How do you explain, using photons, the numerous spectral lines (Figures 2 and 3) observed when a greenhouse gas absorbs energy from the electromagnetic field, given that these are the resonant frequencies of the gas molecule? The photon is a very handy mathematical concept for calculating electromagnetic energy, but there are many reasons to wonder whether it can be a physical reality.

This confusion over radiant energy being a function of frequency rather than amount of bandwidth has been with us since Maxwell (1865). Langley (1889) wrote “*the reader is reminded that the words ‘infra-red’ have obtained an extension of meaning since we have been able to show in previous memoirs, … the vast amount of the energy in this region (which, in the case of the sun, is over 100 times that in the ultra-violet)*”. On the contrary, for $E=h\nu$, the energy of solar ultraviolet-B is nearly 50 times greater than the energy of terrestrial infrared radiation absorbed most strongly by CO_2. You know, from personal experience, that you get much warmer standing in sunlight than standing in moonlight or standing outside at night with terrestrial infrared welling up around you.

Thermal energy in matter is observed to be a broad spectrum of frequencies of oscillation. These oscillations on the surface of matter induce electromagnetic radiation consisting of a broad spectrum of frequencies of oscillation. This radiation, when absorbed by matter, increases the amplitudes of oscillation in the absorbing matter. There is no need to hypothesize waves or photons.

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