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Wagging the Dog

Tyndall, J. (1861). On the absorption and radiation of heat by gases and vapours, and on the physical connexion of radiation, absorption, and conduction. *Philosophical Magazine Series 4*, **22**, 169–194, 273–285. 12 pages.

Technical Innovation

John Tyndall labored long and hard, he would have us be assured, to improve the technology for measuring the interactions of gas molecules with infrared radiation, what he called "radiant heat." He measured the absorption of IR by the cool gas, and the emission of IR by the gas when it is heated. Gases in his study that absorb also emit a principal now known as Kirkhoff's law. Tyndall also demonstrated that when a gas is very dilute or at low enough pressure, the absorption increases proportionately with the concentration of the gas, but at a high enough concentration the gas absorbs all of the IR, a phenomenon now called the band saturation effect.

Figure 2.1 results from Tyndall's Tables I and II, demonstrating the difference between a saturated and an unsaturated gas. When the gas is unsaturated, the absorption of the radiation by the gas varies linearly with the amount of gas in the cell. At high gas concentration, further increases in the amount of the gas have little effect on the IR absorption.

The basic idea behind the measurement of infrared energy flux or intensity is still used today, for example, in electronic thermometers that peer into a baby's ear (much recommended over the other method). The incoming radiation warms up one pole of a device called a thermopile. A thermopile has two poles, and it produces a measurable voltage that is proportional to the temperature difference between the poles. A thermopile is a collection of thermocouples, consisting of junctions of dissimilar metals at each pole, wired together to produce a stronger, more easily measured voltage.

Tyndall measured the signal from the thermopile using a galvanometer, which measures electrical current, a device now usually called an ammeter. Presumably, the voltage from the thermopile was driven through a resistor to produce an electric current. The galvanometer consists of a rotating part on springs, and a fixed part. A set of permanent magnets are mounted on the fixed part, surrounding the rotating part. The electricity flows through a coil on the rotating part, inducing a magnetic field and causing the rotating part to twist slightly, straining against the springs. A needle mounted on the twisting part allowed a measurement to be recorded, which Tyndall expressed in units of degrees of deflection.

Many of the technical improvements that Tyndall developed have to do with improving the sensitivity of the galvanometer. In addition to improving the intrinsic sensitivity of the device by replacing the dye in the silk used to insulate the coil (he claimed it had a magnetic field), Tyndall figured out that if he balanced the two sides of the thermopile against each other, he could obtain greater sensitivity of measurement. Let us suppose that a gas absorbs 1% of an incoming IR beam, and you use the thermopile to compare the intensity of the IR beam to the intensity of IR from the cool surroundings, just the lab walls shining in. To measure the impact of the absorbing gas,

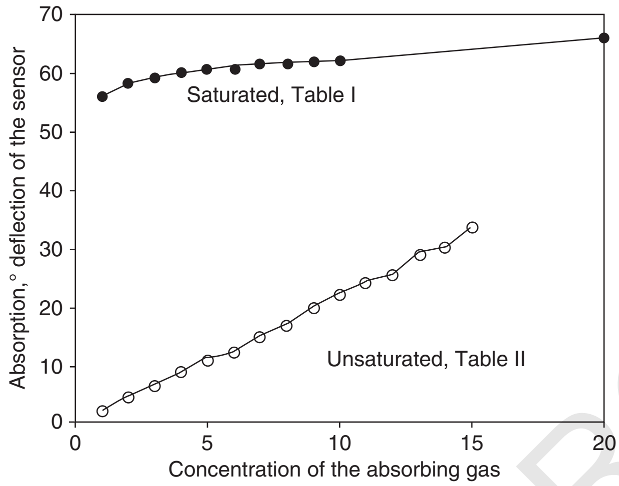

Fig. 2.1 **Tyndall's measurements demonstrated the band saturation effect, which causes the absorption of light to be insensitive to the amount of gas that the light traverses, if the gas concentration is high enough. If virtually all the light is absorbed, then adding more gas has only a small effect. The difference between the data in Tables I and II is that the concentrations of gases in Table I are higher, and therefore saturated. Tyndall also recognized that the atmosphere could be either saturated or unsaturated.**

you would have to be able to detect a small signal change of only 1%. Tyndall's idea was to balance the two sides of the thermopile against each other, by setting up an IR source to the reference side that is the same intensity as the beam on the sample side, before the gas has been introduced. The 1% change in the absolute intensity of the sample beam produces a much larger relative signal against the balanced reference beam of the thermopile. Tyndall needed this increased sensitivity to detect the IR absorption of dilute mixtures of greenhouse gases, such as in air.

Conceptual Breakthroughs

Tyndall's laboratory labors were well informed, driven even, by questions of the Earth's climate and the greenhouse effect. The most jaw-dropping implication of his study was that most (or, as it subsequently turned out, essentially all) of the greenhouse activity of the atmosphere is due to a few trace gases such as water vapor and carbon dioxide. Tyndall realized that this discovery opened the door to an easy way to change the climate of the Earth through time. Instead of waiting for the entire size or mass of the atmosphere to change, all that needs to change is the concentration of a few trace gases. When it comes to the trace greenhouse gases, a little goes a long way.

Scientists are still working out the factors that control the CO_2 concentration of the atmosphere. Tyndall nods to CO_2 as a potential agent of climate change, but points out in particular the variability of the humidity of the air, and speculates about the role that water vapor as a greenhouse gas might play in climate. As it turns out, the Earth's temperature is affected by greenhouse forcing from humidity, but the averaging of the temperatures over wide areas and around the year tends to eliminate much simple correlation between temperature and day-to-day humidity variations. Tyndall was correct in his conclusion that water vapor is the most powerful greenhouse gas in the atmosphere, but as it turns out water vapor is not considered to be a primary climate forcing, because the average water vapor concentration of the atmosphere is now thought to be closely controlled by the hydrologic cycle, in that if the air gets too humid, it rains. For this reason running a garden sprinkler does not lead to global warming in the way that running a gasoline-powered leaf blower does (by emitting CO_2). However, water vapor acts as a positive feedback in the climate system, amplifying a temperature change driven by any other factor such as rising CO_2 concentration.

Tyndall took a few steps in the direction of working out why some gases interact with IR light and some do not. The IR-transparent ones are all simple single-element gases like O_2, N_2, and H_2. The molecular formulas of the gases were not available to Tyndall, so he assumed these to be simple atoms, as opposed to molecules comprised of multiple copies of the same element. The IR behavior of these gases was very different from that of the compound gases like H_2O, CO_2, and ethylene (C_2H_4), which he found to be IR active. Tyndall interpreted his results as evidence for chemical bonds, as in, for example, ammonia as opposed to a mixture of nitrogen and hydrogen gases. The flaw in his conclusion is that diatomic molecules such as N_2 and O_2 have chemical bonds also, it turns out, but are not greenhouse gases because their electronic symmetry when they vibrate does not present an electric dipole to the electromagnetic field, and thus does not produce light. Tyndall phrased it that the compound gases "present a broader side" to the mysterious, gelatinous, gooey substance known as the ether, the medium within which light was thought to propagate, while "the simple atoms do not, – that in consequence of these differences the ether must swell into billows when the former are moved, while it merely trembles into ripples when the latter are agitated. …" It is difficult to read this sentence today without a bit of mirthful joy, but if we substitute "electromagnetic field" for "ether," and "electromagnetic radiation" for the billows and ripples, Tyndall's intuition was clearly in the right direction.