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The Influence of Heat Source IR Radiation on Black-Body Heating/Cooling with Increased CO_2 Concentration

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Abstract

This study deal with interactions between thermal and radiative energy flow in experimental situations of varying complexity. Of special interest is how IR energy, re-emitted from CO_2 gas, behaves in an earth/atmosphere simulated setup. Such an experiment was performed by Hermann Harde and Michael Schnell where they show that IR radiation emitted from CO_2 can warm a small black-body metal plate. In a control experiment, we verified this result. However, in their experiment, the amount of IR radiation from the heating element was strongly attenuated. In a modified experiment, where IR emission from the heating source is present, no heating but a slight cooling of a black object is found when air is replaced by CO_2. The modified experimental situation is also more like the earth/atmosphere situation. The presence of IR radiation from a heated surface (like when the sun heats the earth's surface) strongly attenuates the heating ability of increasing backscatter from increased amount of CO_2 in the atmosphere. This result has consequences for the climate change models used by IPCC.

Keywords

Greenhouse Effect, CO_2 Backscatter, IR Radiation

1. Introduction

In 1859 John Tyndall [1] published his famous experiments, showing how infrared (IR) radiation was absorbed in "greenhouse" gases like water vapor, carbon dioxide (CO_2) and methane (CH_4). He concluded that absorbed heat in these gases warmed the atmosphere, laying the foundation for the theory that increased CO_2 in the air leads to a warmer climate, *i.e*. the "Greenhouse Effect". Later, in 1896, Svante Arrhenius [2] calculated how much the temperature of the surface of the Earth would increase when the CO_2 concentration increased. Even today his theory is still the basis of most climate studies around the world.

The Greenhouse Effect can be described as follows:

1) The atmosphere is transparent to short-wave solar radiation that warms the surface of the Earth.

2) The heated soil and water emit long-wave radiation (IR radiation).

3) The IR radiation is captured by greenhouse gases (H_2O, CO_2 and CH_4) and then sent out (emitted) in all directions.

4) Most of the emitted IR radiation is leaving the atmosphere, but a part of it (back radiation or backscatter) from greenhouse gases returns to the Earth's surface and is absorbed.

5) The absorbed backscatter leads to increased surface temperature that heats the air.

6) Humans' increased emission of greenhouse gases, mainly CO_2, leads to an enhanced Greenhouse Effect.

This explanation is used by IPCC (Intergovernmental Panel on Climate Change) [3] and other research [4] [5] [6]. Points 1 to 4 have been verified by several types of measurements, both by satellites and at ground level [7] [8]. However, no direct measurement was made of the resulting heating of Earth's surface. IPCC admits that the amount of heating is still discussed and that the enhanced greenhouse effect from increased amount of CO_2 has, until recently, only been confirmed by empirical evidence [9]. But one experiment, clearly showing that CO_2 can heat a black-body, was performed by Harde and Schnell in 2020 [10]. This experiment was the basis for the experiments presented here.

2. The Harde/Schnell Experiment

Harde and Schnell [10] have presented an experiment that should explain how added amounts of greenhouse gases (like CO_2) heat the surface of the Earth. Their experimental setup is shown in **Figure 1**, consisting of a cylinder-shaped tank, which on the inside consists of polished aluminum. Internal height/diameter is 111 cm/36cm. The doom shaped top part is heated to 30˚C while a cooled (−11.4˚C), black plate is placed at the bottom. Compared to the earth/atmosphere situation this setup is mounted upside-down. Close to the top of the tank is a small black-painted aluminum plate placed, representing the Earth's surface (the Earth Plate EP). This setup leads to a vertically stable temperature gradient, similar to the lapse rate gradient of the troposphere. The cold plate represents the top of the troposphere.

The cylinder was first filled with dry air and left to stabilize thermally. When CO_2 was added to the air in the tank the temperature of the Earth Plate increases. This is seen in their **Figure 10(a)**. The highest concentration of CO_2 used

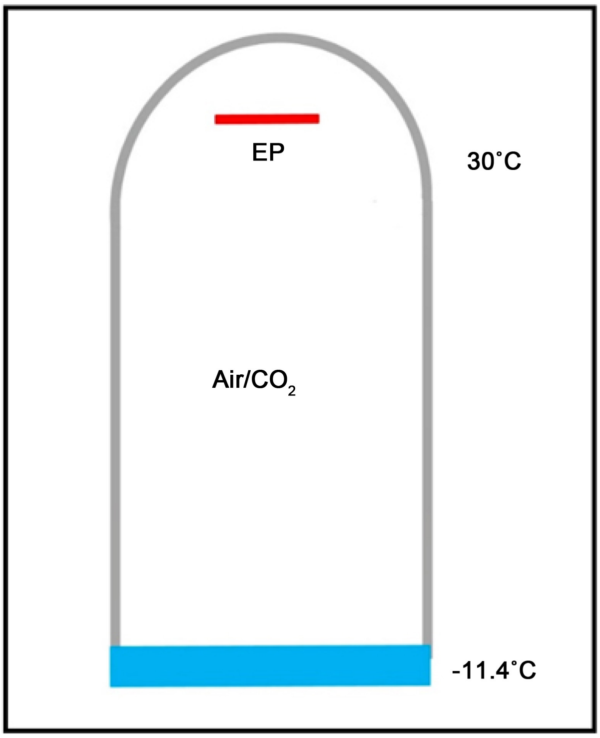


Figure 1. The experimental setup used by Harde and Schnell [10].

was 20%, leading to an increase of the Earth Plate temperature of 1.18˚C.

It is of interest to find how much the temperature of the Earth Plate will increase with CO_2 concentration close to 100%. If we compute the temperature increment ΔT in their **Figure 10(a)** as function of Log(c), where c is the concentration of CO_2 in %, we get:

$$\Delta T = 0.6075 \times \text{Log}(c) + 0.3853 . \quad (1)$$

We can now calculate the temperature increment for CO_2 concentrations above 20%. For c = 100% we expect to get a temperature increment of 1.60 degrees.

In the experiment, presented below, we wanted to make a setup similar to theirs where we could repeat the heating with increased CO_2 levels. This experiment was also based on the experience obtained from a previous experiment where the interaction between IR and thermal energy was studied [11].

3. The Two-Envelope Experiment

In this experiment [11], two objects, made from black-painted and highly polished Al foil envelopes respectively, were placed in a chamber where the air temperature is controlled. The heating plate, used to heat the air in the chamber, was placed in the bottom of the chamber. Like in the Harde/Schnell experiment it was covered with Al-foil in order to suppress IR radiation. IR radiation from the (cold) room surrounding the heated chamber enters it through the IR transparent walls and roof of the chamber. When heated by the air in the chamber the black object becomes about 36% colder than the non-IR absorbing object. The temperature of the Al-foil envelope was shown to be the same as that of the air in the box. However, when the two envelopes are cooled by cold air in the chamber, the black one becomes ca. 36% warmer than the non-IR absorbing Al-foil envelope. The result is shown in Figure 2, copied from Figure 8 in the two-envelope paper. It shows that cold and warm black envelope temperatures follow a common straight line.

4. The Modified Harde/Schnell Experiment

Based on the results from this and the Harde/Schnell experiment a new one was performed. The new setup is shown in Figure 3. A box was made of 5 cm thick, white Styrofoam boards. Inner dimensions of the box was L/B/H = 65 cm/30 cm/25 cm. In front of the box a window was mounted, consisting of thin, IR transparent plastic foil made of LDPE (low-density polyethylene), which transmits nearly all of the IR radiation [12].

The inside of the walls were covered with polished, thin Al-foil. A 20 cm × 25 cm black-painted aluminum heating plate, heated from behind by power resistors, was mounted on the rear wall of the box. The heating plate (and the rest of the rear wall) was also covered by Al-foil, as done in the two-envelope experiment [11]. As in this experiment we used two thin 7 cm × 7 cm envelopes, one made of thin, polished Al-foil and one of black painted Al-foil. The black envelope represents the Earth Plate in the Harde/Schnell experiment. Each envelope contained a calibrated thermocouple, type K. The envelopes were placed in the middle of the box, 10 cm below the roof, and attached to the roof by the thermocouple cable. When the air in the box is heated to a stable, high

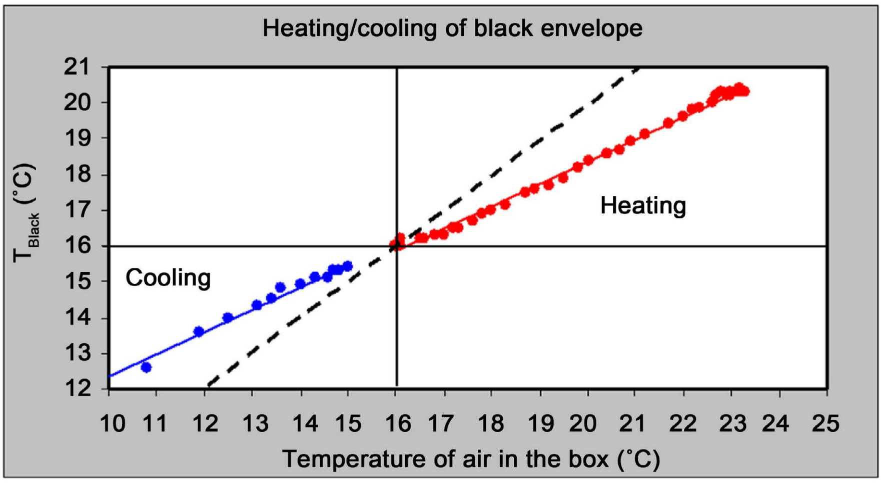


Figure 2. Black envelope temperature as a function of air temperature. Red circles show temperature for the black envelope when the air in the chamber is warmer than the surroundings (at 16˚C), while blue circles show temperature for the black envelope when the air in the chamber is colder than the surrounding room temperature. The dashed line shows the temperature of the polished Al-foil envelope.

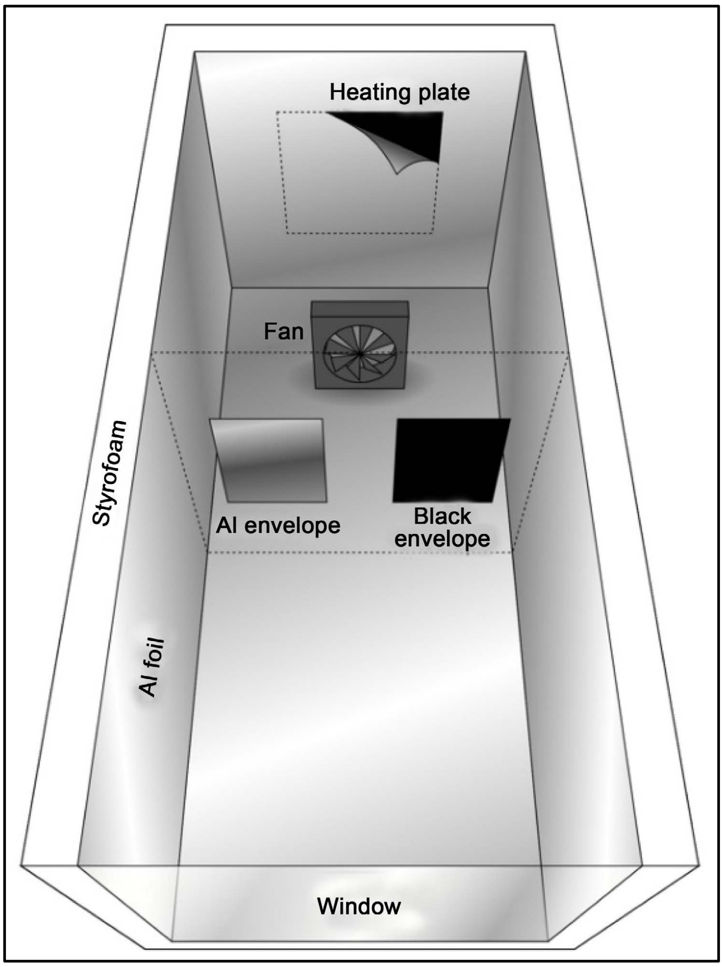


Figure 3. Experimental setup, seen from above, with the top plate removed.

temperature we get a temperature gradient between the air and the cold room outside the window. In this setup the cold room replaces the cold plate in the bottom of the tank used by Harde and Schnell.

Water vapour is a powerful absorber of IR radiation. To dry the air in the box a small bag of water vapour absorbing silica gel was placed in the box. A small fan, running at low speed, was placed close to the silica gel bag. The fan was blowing against the rear of the box, thereby reducing the temperature difference between the front and rear end of the box. During the first 30 minutes of heating the fan was turned on in order to dry the air in the box.

4.1. Experimental Results for the Modified Harde/Schnell Experiment

We first present the results with the heating plate covered by Al-foil, in order to check if this will lead to similar results as obtained by Harde and Schnell.

4.1.1. Heating of the Air and the Envelopes in the Box with Al-Foil Covering the Heating Plate

In the two-envelope experiment [11] the heating of the air in the box decreased the temperature of the black envelope, compared to air temperature. The heating of the black envelope decreased linearly about 36% with increasing air temperature. See **Figure 5** in the report. A similar effect was found in the new experiment. See **Figure 4** where the temperature T-Black of the black envelope minus air temperature (T-Alum) is plotted as function of air temperature. As in the two-envelope experiment the black envelope becomes colder than the surrounding air, but only by 20%. The probable reason is that the loss of IR energy to the cold room outside is through a window much smaller than the area of walls and roof in the two-envelope experiment.

4.1.2. Replacing Air with CO_2

Figure 5 shows that, after the temperature had stabilized, the air in the box was replaced by CO_2 after 243 minutes. Before filling CO_2 the black envelope was 4.33 degrees colder than the surrounding air. When (cold) CO_2 is filled the temperature fluctuates, reducing the temperature difference shortly to zero. We then waited until it stabilized again at −3.57˚C, ca. 15 minutes after filling CO_2.

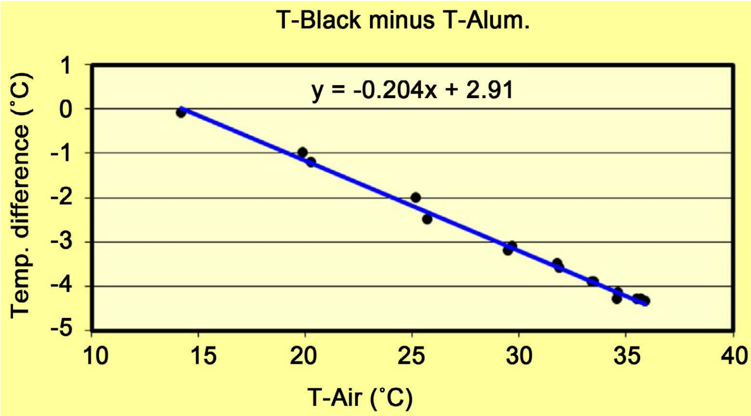


Figure 4. Heating the air in the box. Air temperature (T-Air) is plotted along the abscissa. Ordinate: The temperature difference between the black and the polished aluminum envelope.

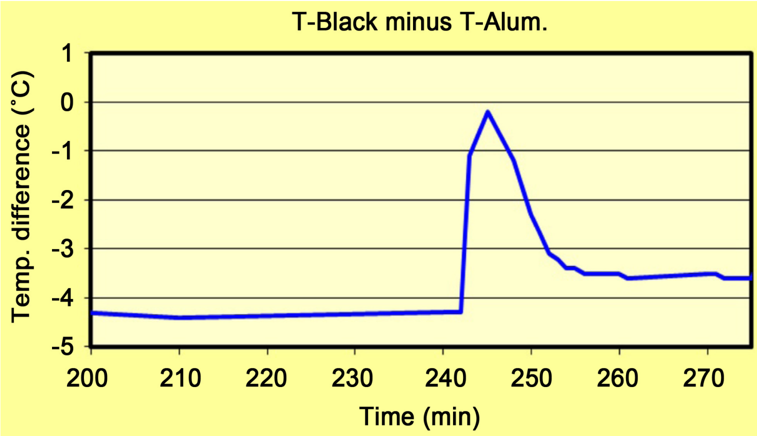


Figure 5. CO_2 was filled after 243 minutes. Filling CO_2 increases the temperature of the black envelope.

Figure 5 shows that, filling CO_2, increased the temperature of the black envelope by 0.76 ± 0.02 degrees! So the CO_2 is heating a black-body. The result is similar but lower than what Harde and Schnell found. From Equation (1) we found that, for 100% CO_2, they should get 1.6˚C heating of the Earth Plate. But the tempeature difference between heating at the top of their container (30˚C) and bottom plate (−11.4˚C) was 41.4˚C. In our case the difference between room temperture outside the window of the box and the air inside was 22˚C, *i.e.* ca. 50% less.

The power input to the heating plate was 30.3 W. **Figure 4** shows that cooling of the black envelope increases linearly when air temperature increases. By increasing the heating power of the black plate to 38.3 W the heating by CO_2 increased ca. 1.7˚C, as shown in **Figure 6**. This value is close to that predicted by Equation (1). Note that the temperature is not stable before filling CO_2, but the gradient is stable enough to predict it, as indicated by the broken line.

5. Removing the Al-Foil from the Black Heating Plate

With the Al-foil removed from the heating plate the experiment was repeated. Now the result changed markedly from the previous one. See **Figure 7**. In this setup, with added IR energy from the black heating plate, the black envelope becomes warmer, not colder than the surrounding air. After 150 minutes of heating of the air in the box the temperature increment stabilizes at 1.1˚C. After filling CO_2 it stabilizes at 0.8˚C ± 0.025˚C, that is, at a slightly lower value than for air alone. So, in this case, adding CO_2 cools the black envelope slightly! The experiment was repeated and the average cooling was found to be −0.22˚C ± 0.03˚C. (Note: During filling the box with cold CO_2 the temperature of the Al-foil envelope drops about 4 degrees, while the temperature of the black envelope drops less than one degree).

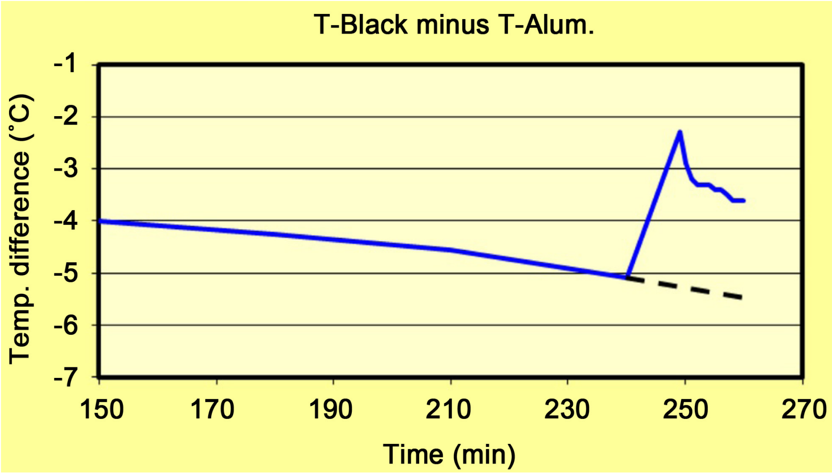


Figure 6. Reduced cooling of the black enveope by CO_2. The temperature after 240 minutes heating was not completely stable, but the reduced cooling of the black envelope by ca. 1.7 degrees was clearly evident when the temperature gradient is extended (broken line).

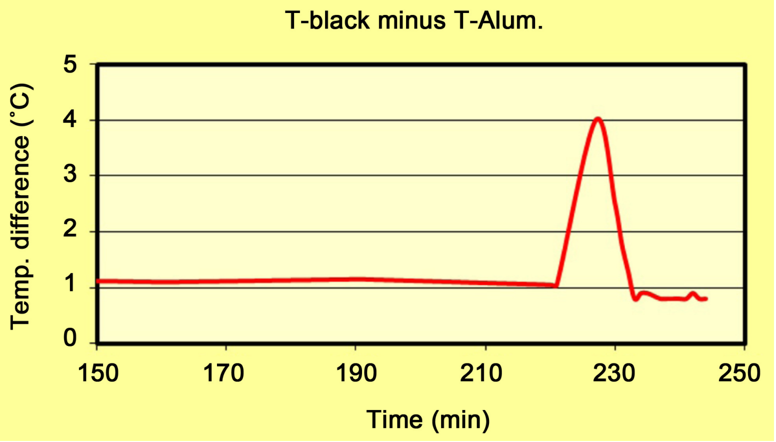


Figure 7. Adding IR radiation from the black heating plate makes the black envelope warmer than the air. CO_2 is filled after 220 minutes.

5.1. Black Napkin Used as a Black-Body Heating Source

Maybe the high heat capacity of the black heating plate, weighting 274 grams, attenuates the ability to heat the black envelope by CO_2? This was investigated as follows:

The rear wall (with the heating plate) was again covered by AL-foil. Then a thin matt-black painted paper napkin was placed on the rear wall. The weight of the napkin was 4.5 grams. Then a new measurement was performed and the result is shown in the Figure 8. Again the same result as for the black metal heating plate was found: Filling CO_2 cooled the black envelope slightly.

5.2. Reduced IR Radiation Flow from the Heating Plate When Covered with Al-Foil

When the heating plate was covered by Al-foil the amount of IR energy flow from it was reduced. Harde and Schnell assumed that about 10% of the IR energy flow from the heat source was emitted by the polished aluminum walls. But they had no IR detector to check this. Therefore a control experiment was performed. The heating plate was removed from the box, placed on a table and covered with Al-foil. The Al-foil was not touching the heating plate but placed ca. 1 cm above it. A thermocouple was placed under the Al-foil in the center of the plate, in contact with the Al-foil. An IR thermopile detector [13] was placed 45 cm above the table at an angle of 45 degrees and pointing at the center of the Al-foil. Ambient (room) temperature was 20.2˚C. The relationship between IR energy flow E in W/m^2 and temperature T in Kelvin is given by the Stefan-Boltzmanns law:

$$E\left(W/m^2\right) = \sigma T^4 \tag{2}$$

where $\sigma = 5.67 \times 10^{-8}$ $W/(m^2K^4)$ is the Stefan-Boltzmann constant. For 20.2˚C we get the IR energy flow to be 419 W/m^2.

The heating of the plate was turned on until the temperature of the Al-foil reached 62˚C. Then the IR thermopile detector measured 424.2 W/m^2, ie an

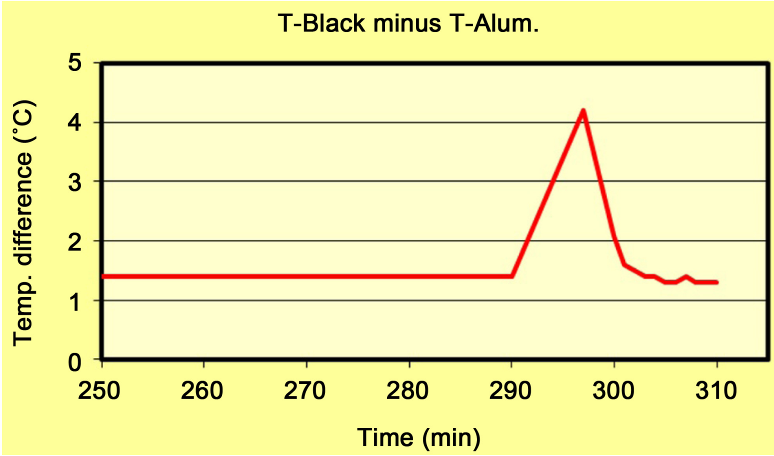


Figure 8. Heating with black-painted napkin covering the rear Al-foil wall. CO_2 is filled after 290 minutes.

increase of 1%.

In Figure 4 the air temperature increased ca. 23 degrees above the ambient temperature. Figure 9 shows that the measured IR energy output is not (or only slightly) increasing for Al-foil temperature increments below 20 degrees.

Figure 9 shows that emitted IR energy from the Al-foil increases ca. 4.6 W/m^2 or 1.6% when the temperature rises to 63˚C. However, the temperature of the black heating plate itself was ca. 88˚C and emitted ca. 960 W/m^2. Only about 0.5% of this value was transmitted! So, covering the heating plate with Al-foil suppresses the IR radiation from it very effectively.

6. Discussion

In the Harde/Schnell experiment (and our modified version) the IR energy radiation from the heating source is strongly attenuated, as shown in Figure 9. In the Earth-Atmosphere-System no such attenuation takes place of the IR energy radiation from the Earth's heated surface.

When CO_2 is filled and heated the IR quanta density increases in the box. This should lead to higher number of absorbed quanta in the black envelope and increase its temperature, but the opposite happen. Lack of increased heating when CO_2 is added has been shown earlier [14] [15], but not cooling. Since filling CO_2 is slightly cooling the black envelope then some energy must be removed from it. This can be explained as follows:

1) The black envelope will absorb a part of the IR radiation emitted by the heating plate.

2) When CO_2 replaces air in the box, it will absorb some of the IR quanta that otherwise would be absorbed by the black envelope.

3) The IR quanta, which is absorbed by CO_2, will then be emitted in all directions. Most of them will not hit the black envelope but will hit the Al-covered walls, be reflected, and leave the box through the window. This cools the black envelope slightly.

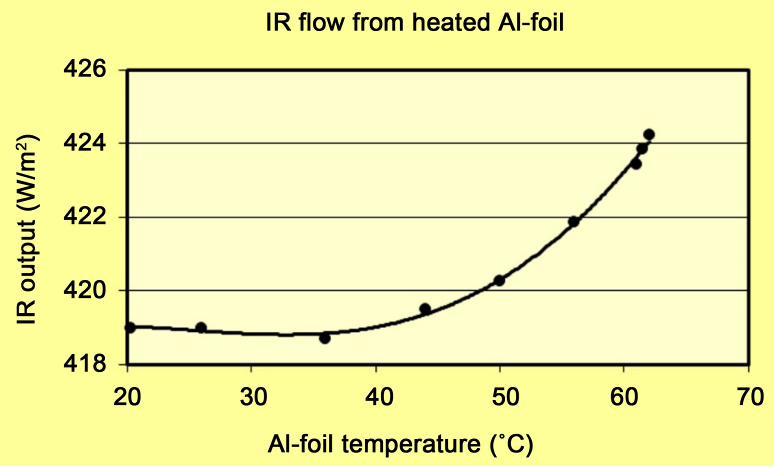


Figure 9. IR radiation flow, reflected from the room walls by the Al-foil and emitted through the heated Al-foil placed above the heating plate.

6.1. Black Napkin Used as a Black-Body IR Energy Radiator

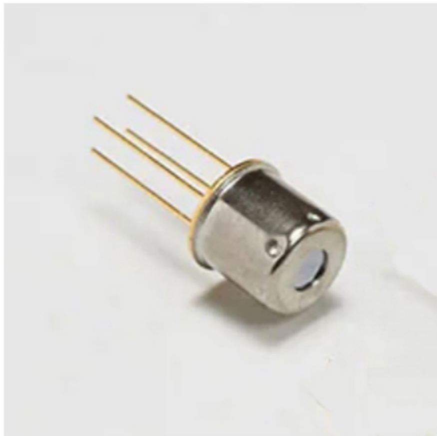
With a low-mass heating source (black napkin) a similar result as for high-mass black-body heating plate was obtained. So, it seems that it is the amount of IR energy radiation from the heating element in the box that is the main source of attenuating heating when CO_2 is present, not influenced by the mass of the heat-source. Therefore it must be some interaction with IR energy radiation from a warm, black source and the IR energy radiation/absorption from CO_2 that lead to the missing heating! The mass of the heat source do not influence the result.

6.2. Comparing the Harde/Schnell Experiment with the Working of an IR Thermopile Detector

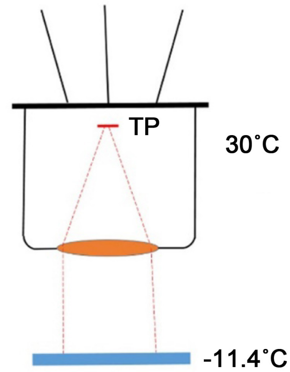
A thermopile IR detector consists of a large number of serial connected thermocouples. The thermopile is mounted in the bottom of a small metal capsule of 8.5 mm diameter [13]. The photo of the capsule in Figure 10(a) shows that it is made of polished metal that reflects IR radiation. On top of the capsule is the IR transparent lens. When the detector points at an IR radiation source of higher temperature than that of the thermopile, then it absorbs incoming IR radiation and is heated. See Figure 11. The heating leads to an increased voltage across the thermopile (TP). When IR radiation from CO_2 enters through the lens, it will also heat the TP. However, if the temperature of the external IR radiation source is lower than the temperature of the detector then IR energy is lost through the lens and cools the thermopile. See Figure 10(b) and Figure 11.

When calibrated (with radiation from a black-body source of varying temperature) it measures IR radiation in W/m^2 from IR radiation sources, including IR emission from excited CO_2 molecules.

To understand how the thermopile detector reacts to all types of IR radiation sources we have opened the capsule. What we then observe is that all the interior walls are made of blank metal, just like the inner walls in the Harde/Schnell



(a)



(b)

Figure 10. (a): Photo of a thermopile IR detector. The lens, passing IR radiation, is seen at the top of the metal capsule. (b): The IR detector, with lens pointing downward at a cold (−11.4˚C) surface.

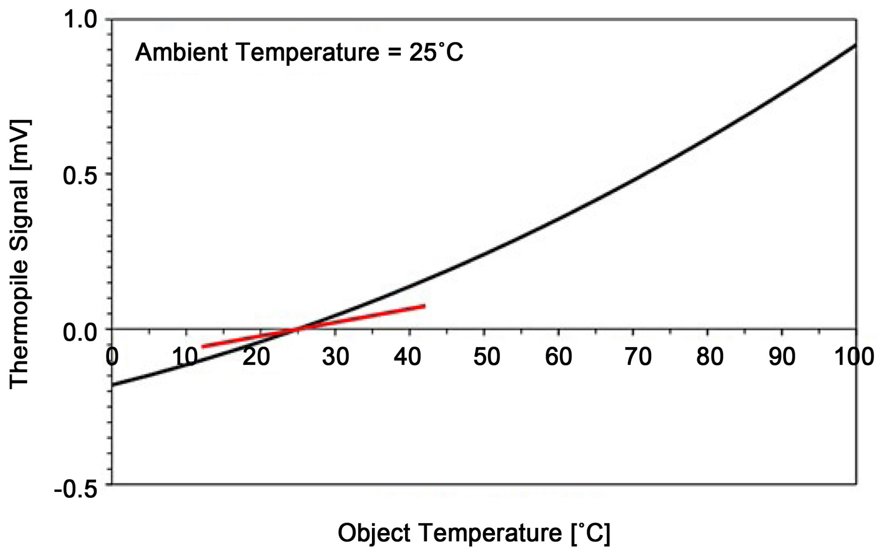


Figure 11. The response in mV of a thermopile when the temperature of the measured black-body source varies from 0 to 100˚C [13]. The thermopile has a constant temperature of 25˚C. See Appendix for explanation of the red line.

experiment. This means that IR energy radiation flow that would be generated with black inner walls are strongly attenuated, just like in the Harde/Schnell experiment! In their case the −11.4˚C IR energy source in the bottom of the tank was colder than the Earth Plate and it lost IR energy and cooled down (like the thermopile in the IR detector).

Figure 10(b) shows the thermopile (TP) detector positioned in a similar way as the experimental setup in the Harde/Schnell experiment. See Figure 1. The IR energy flow from the TP to a cold (−11.4˚C) black surface is measured when the temperature of the IR detector is 30˚C. The thermopile (TP) is cooled in a similar way as the Earth Plate in the Harde/Schnell experiment.

7. Conclusions

That the presence of CO_2 in the box, with the heating plate present, lead to cooling of a black body (the black envelope) was an unexpected surprise.

The presence of IR radiation from a heated black-body suppresses the heating ability of IR radiation from CO_2. This result is also unexpected. From the Stefan-Boltzmanns law and the climate models used by IPCC, we expected to get heating from IR quanta emitted by increased concentration of CO_2 gas. It seems that, to obtain a heating effect from increased CO_2 concentration, we have to remove most of the IR radiation from the ground (heated by the sun), for instance by covering the ground by Al-foil!

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Appendix 1. Filling CO_2 inside an IR Thermopile Detector

We have compared the experimental setup of Harde and Schnell with the construction of a thermopile detector. See Figure 1 and Figure 10(b). Both operate with smooth metal surfaces inside the metal containers. The functionality is similar for both, even when the volume of the Harde and Schnell container is ca. 130 liters, but less than one milliliter for the IR detector!

When CO_2 is added in the Harde/Schnell experiment the cooling of the Earth Plate is reduced. We expect the same to happen to the thermopile (TP) in the IR detector. When the object to be measured is colder than the IR detector, then the thermopile is cooled. Cooling a thermopile will lead to a negative voltage across it, as shown in Figure 11. We assume that, adding CO_2 inside the detector capsule, will reduce the cooling of the thermopile. This is indicated by the red line in Figure 11. By extending the red line to higher IR source temperatures we see that, filling CO_2, should reduce the heating of the thermopile! This assumption is made because we expect a smooth, near-linear transition of the TP response curve for colder and warmer IR radiation sources, as shown with the red line in the figure. A possible explanation of the cooling might be that CO_2 gas will absorb incoming IR quanta that otherwise would be absorbed by the TP. Only a few of the quanta emitted from CO_2 will hit the TP and the rest will be reflected from the walls inside the detector and leave through the lens. (See Figure 10(b))

Appendix 2. Heating and Cooling CO_2 in the Two-Envelope Experiment [11]

In the two-envelope experiment [11] the heating plate was also covered with Al-foil. The result from either warming or cooling the air in the box is shown in Figure A1. It shows that, for colder and warmer air in the box, compared to the

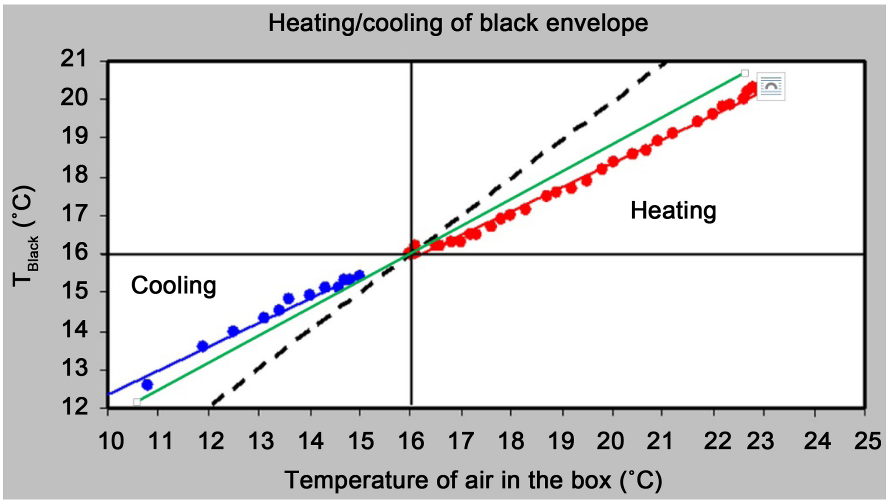

Figure A1. Substituting air in the two-envelope experiment with CO_2. The green line indicate the expected temperature of the black envelope when the CO_2 temperature in the box is colder or warmer than the surrounding room temperature of 16˚C.

temperature of the surrounding room, the temperature of the black envelope closely follows a common straight blue/red line. However, we did not replace the air with CO_2 in this experiment. But, based on the result with CO_2 in both the Harde/Schnell and our experiment, we can make the following assumption: When CO_2 is filled in the box, and it is warmer than the 16˚C surround, then we expect less cooling of the black envelope than with air in the box. This is indicated by the green line in the diagram. This straight line is extended to temperatures lower than that of the surround. Here the green line indicate that the black envelope will be colder than when the box is filled with air.