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Climate change and our responsibilities as chemists

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Abstract For almost all of 4.5 billion years, natural forces have shaped Earth's environment. But, during the past century, as a result of the Industrial Revolution, which has had enormous benefits for humans, the effects of human activities have become the main driver for climate change. The increase of atmospheric carbon dioxide caused by burning fossil fuels for energy to power the revolution causes an energy imbalance between incoming solar radiation and outgoing planetary emission. The imbalance is warming the planet and causing the atmosphere and oceans to warm, ice to melt, sea level to rise, and weather extremes to increase. In addition, dissolution of part of the carbon dioxide in the oceans is causing them to acidify, with possible negative effects on marine biota. As citizens of an interconnected global society and scientists who have the background to understand climate change, we have a responsibility first to understand the science. One resource that is available to help is the American Chemical Society Climate Science Toolkit, www.acs.org/climatescience. With this understanding our further responsibility as citizen scientists is to engage others in deliberative discussions on the science, to take actions ourselves to adapt to and mitigate human-caused climate change, and urge others to follow our example.

1. Introduction

The Earth's environment has changed naturally and dramatically many times during its 4.5 billion year history. Humans have been changing the environment for the last few thousand years. We domesticated animals for food, transportation, and labor. We invented agriculture that changed the surface of the planet and reduced the percentage of the population required to produce food. This, in turn, allowed the rise of towns and cities and the development of crafts and manufacturing and civilization, as we know it. During most of this period of human history, environmental changes were largely local. In some areas, for example, deforestation occurred to create more agricultural land and to provide firewood for heating and cooking and in others animals were driven to extinction by overhunting for food. But human impacts had not reached a global level.

This changed about 250 years ago with James Watt's invention of the steam engine that initiated the Industrial Revolution. Suddenly, enormous amounts of power that did not depend upon human, animal, or water power, were available essentially anywhere, including for transportation (the steam locomotive). All that was required for these engines was an energy source and burning readily available coal satisfied this

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need. About a century later, the discovery of fossil oil (and natural gas) and then the invention of the internal combustion engine added an even more convenient source of power, especially for transportation (the automobile and airplane). The availability of this power and new raw materials, especially oil, transformed the world. From pharmaceuticals and synthetic polymeric goods to pesticides that make much modern agriculture possible, human ingenuity has capitalized on these resources.

More profoundly, our knowledge of the world has deepened and provides us with a great deal more insight into its history and our place within it. Scientifically, our achievements have been aided by both conceptual and technical advances—atomic and quantum models, electromagnetic theory, and spectroscopy that bring these concepts together and provide an intimate view of the molecular world. These advancements help us know much about the natural environmental changes brought about for example by the interactions of the Earth with the sun and its sister planets. This knowledge also makes us aware of the ways human activities influence natural processes and what the consequences can be for the planet and our lives. As scientists, our responsibilities are not only to understand the natural and human-influenced processes, but to help others understand them, and work with them to adapt to and reduce any negative consequences.

2. Climate change science

Accompanying all the knowledge and wonders made available by the Industrial Revolution is a large efflux of carbon dioxide to the atmosphere from the combustion of fossil fuels: coal, oil, and natural gas. Some of this gas dissolves relatively rapidly in the oceans or is taken up by photosynthesizing organisms and some enters the very long-term geochemical carbon cycle. The rest remains in the gas phase and is mixed fairly uniformly by convection and wind throughout the atmosphere. Evidence from air trapped in ice cores indicates that the pre-industrial level of carbon dioxide in the atmosphere was about 280 ppm. In mid-2013, the carbon dioxide level reached almost 400 ppm, (Fig. 1).

The human-caused release of carbon dioxide, mainly from burning fossil fuels, and its increasing concentration in the atmosphere and oceans are global phenomena with consequences for the environment of the entire planet. The basis of the consequences of concern here is interaction of atmospheric carbon dioxide with infrared radiation and the acid–base reactions of its aqueous solutions.

The Earth's atmosphere is essential for maintaining a livable environment. Radiant energy from the sun, mainly in the visible region of the spectrum, where atmospheric gases are transparent, is absorbed by the Earth's surface and warms it. The warmed surface radiates energy back into space, mainly in the infrared region of the spectrum. The balance between the incoming solar energy and the outgoing infrared energy determines the temperature of the planet. The presence of infrared absorbing gases in the atmosphere retains some of the infrared energy and requires a higher surface temperature to maintain the incoming-outgoing balance. This "greenhouse effect" keeps the planet warmer than it would be in the absence of infrared-absorbing gases and makes life, as we know it, possible.

Infrared absorption and emission by carbon dioxide are the major control mechanism for the atmospheric greenhouse effect. The increasing concentration of carbon dioxide increases the greenhouse effect, so the Earth retains more energy. Fig. 2 shows where this energy has gone over about the last half century—more than 90% into the oceans, which are an enormous, high heat capacity reservoir, with smaller amounts into melting ice (in glaciers and the polar regions), and warming the land and atmosphere.

The observed environmental changes include increasing sea level as the oceans warm and expand and more water is added from melting land ice, increasing loss of Arctic sea ice affecting the atmospheric jet stream and northern hemisphere weather patterns, and increasing average temperature of the Earth's surface – usually characterized as "global warming." This surface warming is shown on the upper plot in Fig. 3 while the lower plot shows the Earth's imbalance in retention of solar energy in terms of climate forcing, the amount of the energy imbalance at the top of the atmosphere. (See the American Chemical Society Climate Science Toolkit for discussions of planetary energy balance, mechanism of the greenhouse effect, energy imbalance, and radiative forcing.) (American Chemical Society Climate Science Toolkit) Note that the forcing and temperature had a modest downward trend for the first 800 years of the past millennium, but both started an upward trajectory that became ever steeper during the 200 years

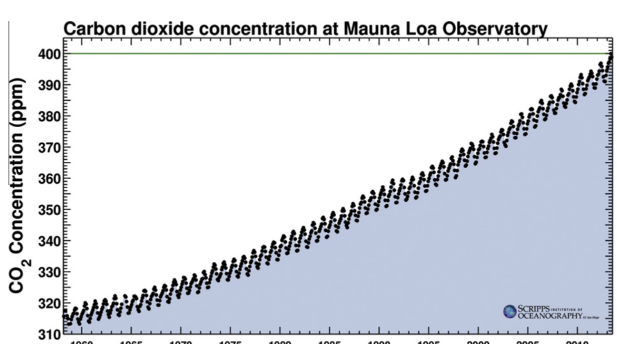

Figure 1 The "Keeling curve," the atmospheric concentration of carbon dioxide from the beginning of measurements in 1958 to mid-2013. (Institute of Oceanography).

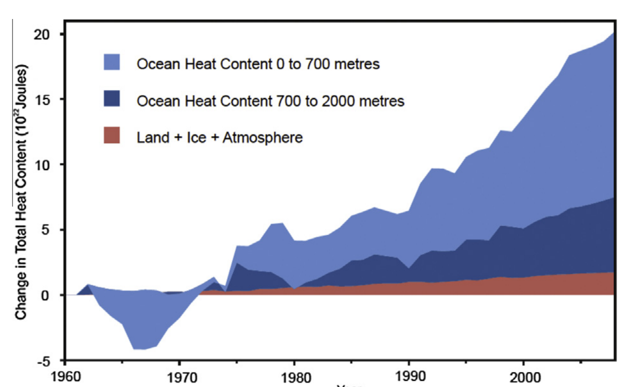

Figure 2 Distribution of the Earth's annual thermal energy content change due to the increased greenhouse effect during the past half century. (Nuccitelli et al., 2012).