DECIPHERING GLOBAL WARMING FOR STUDENTS AT THE SECONDARY STAGE

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Global warming is at the core of climate change. Therefore, understanding global warming is crucial to understand climate change and its adverse impacts so that appropriate measures can be taken up. However, the term, 'global warming' is commonly used by all and sundry, it is hardly understood by most including those students, who have studied about it. This is because global warming is the outcome of numerous factors, events and interactions that happen in the atmosphere which are complex in nature and complicated to explain. As a result, appropriate resources are not easily available that are suitable for students of different stages. Keeping this in view, the article attempts to present global warming comprehensively and holistically in such a manner that secondary stage students will be able to understand.

Keywords: Global Warming, Climate Change, Energy Balance, Greenhouse Effect, Secondary Stage

Introduction

Climate change resulting from global warming is undoubtedly one of the most, if not the most, critical global challenge of the day. This unprecedented situation that humanity is trying to tackle is attributed mainly to anthropogenic activities. The impacts of climate change are so far-reaching that we have no choice but to find ways to mitigate it and empower ourselves to adapt to it. It will require every nation, community and individual to contribute towards its mitigation and adaptation. In this context, the need for climate change education cannot be overemphasised. Kuthe et al. (2019) had also highlighted the need to educate children and teenagers and sensitise them towards climate change issues as they will be responsible for dealing with the environmental and societal consequences of climate change. Yet, contrary to this need, their study about teenagers' climate change awareness in Germany and Austria found students' awareness level to be poor. Similarly, Shepardson et al. (2011) in their study about students' conceptions about the greenhouse effect, global warming and climate change among secondary stage students, found that students are confused about greenhouse effect as well as the kind of radiation involved in the greenhouse effect. Similar results were found among students in secondary stage in Singapore (Chang, 2014) and by Sah and Bellad (2015), wherein they found that less than half of the students in their study area in Karnataka stated that greenhouse gases are a major cause of global climate change. However, this problem is not restricted to students. Handling climate change has been found to be a challenge to environmental educators, since it is an issue that is characterised by controversy, uncertainty, interdisciplinarity and complexity (Ratinen, 2013). Therefore, it is of utmost importance that resources related to climate change should be developed in such a way that all such concerns are addressed. As such, the first step in this direction will be to help students understand what is causing global warming, which is leading to climate change.

In spite of the term 'global warming' gaining so much popularity, being one of the most popular searches on Google around 2007 to 2009[1], we know that it is not easy to understand how exactly global warming occurs. This is because several processes, interactions and events occur simultaneously leading to global warming, which are complex in nature and complicated to understand. Although there are umpteen number of resources available in print and on the internet, resources which are appropriate or suitable for students in different stages of school education in terms of content and depth are hard to find. The relevant resources are not lodged at one site, website, textbook, etc., and are available in bits and pieces. As a result, students and teachers for that matter have to depend on different sources to gain knowledge about global warming or climate change as is evident from a study in Finland by Ratinen (2013), where it was found that student-teachers mentioned school, TV, radio, press and university studies as sources of their knowledge about greenhouse effect. However, all such sources seemed to have been inadequate to have conceptual clarity on greenhouse effect, since only 4 per cent of the respondents conceptualised the concept in a scientifically correct way. While in an online survey of Colorado public school science teachers (n=628) on the topic of climate change instruction, it was found that Colorado students learn about global warming in the following school subjects—environmental science, earth science, life science, social studies, geography, physical science, chemistry, economics, physics, language and arts but majorly in the first three subjects (Wise, 2010). Similar observations were made by Chang (2014) among students in secondary schools in Singapore, where students were said to have gained the knowledge of climate change from different sources, such as school, TV, internet, newspapers, etc., but only 2.5 per cent had accurate understanding about the relationship between greenhouse gases and global warming, indicating the shortcomings in the resources, which students had access to. Such shortcomings are also evident in the existing textbooks developed by NCERT, where except for the mention of the term global warming, or a brief explanation about greenhouse effect, an attempt to explain the concept of global warming meaningfully was found to be wanting. This is corroborated by Shimray and Shirol (2020) in their study

[1] https://yaleclimateconnections.org/2011/10/what-web-searches-reveal-about-global-warmingand- us/#:~:text=Searches for "global warming" peaked in 2007, during the, Truth," attained widespread attention. for !global warming" peaked in 2007, during the, Truth," attained widespread attention.

on students' knowledge about climate change, in which they found that although greenhouse effect and global warming were included at several places in the curriculum developed by NCERT from Classes VI to XII, in many instances, the concepts were merely included as a 'passing statement' as can be seen in Science textbooks for Class VII (NCERT, 2007, p. 216), Class VIII (NCERT, 2008, p. 61, p. 73, pp. 242–243), Class X (NCERT, 2007a, p. 249, p. 279), Class XII Biology (NCERT, 2007b, pp. 280–281). The content in Science Class IX textbook (NCERT, 2006, pp. 198–200) was found to be a little more elaborate but was insufficient for holistic understanding of global warming. Keeping this in view, this article has been written to explain global warming with students at the secondary stage as the target audience. It is envisaged that this comprehensive write-up will help students understand the phenomenon of global warming holistically with systems thinking perspective as they learn to appreciate the interconnectedness of the various components, processes and events involved. In addition, it will also serve as a useful reference for curriculum developers.

Understanding the Science of Global Warming

As we know, by global warming, we mean the increase in the average global temperature. This increase is clearly evident, since the late 18th century following the industrial revolution as the world increasingly relied on fossil fuels as a source of energy to run the industries in different sectors, especially in manufacturing and transport. Hence, global warming that we are experiencing today is attributed to human activities or is considered to be human-caused. While the details as to how this increase in global temperature occurs is complex, fundamentally it occurs due to the disruption in the energy balance. To be more specific, it occurs because the amount of outgoing energy from the earth's surface and its atmosphere into the space is less than the amount of incoming solar energy. How this happens involves several processes and interactions, which are invariably incorporated, in bits and pieces, as part of the physics and chemistry curriculum. All such processes and interactions leading to global warming are sequentially discussed in the subsequent sections.

Box 1: Emission or radiation from an object is dependent upon temperature

Any object with a temperature greater than absolute zero (0 K or -273°C) emits radiation. When an object gets heated, the atoms or molecules that make up that object, collide at an increased rate. As the atom or molecule relaxes back to its original state, it gives up extra energy by emitting photon. This emission of energy in the form of photon is called thermal radiation. In other words, a thermal radiation is an electromagnetic radiation (EMR) emitted from an object due to the heat of the object. Depending upon the temperature of an object, the range and nature of the radiation it emits differ. A hotter object emits radiation of shorter wavelength and greater energy than an object at lower temperature. For example, the Sun, having an average temperature of 6000 K, emits shortwave radiation (peaking in the visible region of Electromagnetic spectrum), while the Earth, at a much lower temperature of 288 K, emits radiation in the far Infrared (IR) region.

Incoming Solar Radiation

It all begins with the Sun. The Sun is the primary source of energy on Earth, vital for sustenance of life. It is directly or indirectly involved in various processes, such as photosynthesis, maintenance of Earth's temperature and wind formation. The Sun's energy (in the form of heat and light) reaches the earth through the process of radiation. Radiation is not limited to the Sun. Any object can emit radiation depending upon its temperature (for details, see Box 1). Transfer of energy through the process of radiation does not require a medium to travel, making it possible for energy from the Sun to travel through vacuum and reach Earth.

Energy in the form of radiation from the Sun behaves like a wave as it travels through space and is known as electromagnetic radiation (EMR). However, when this solar radiation interacts with matter (such as molecules of a gas) in the atmosphere, it acts like particles. These particles, called photons, are able to transfer energy to the molecules they encounter. In this process, EMR is emitted in the form of thermal radiation (see Box 1 for detail). This wave-particle duality of light is a characteristic of EMR.

EMR encompasses a wide range of energy emitted by the Sun, which is generally represented in the form of an electromagnetic spectrum (EMS) (Fig. 1). Incoming solar radiation, which falls in the region of ultraviolet (UV), visible and a limited portion of IR energy, is collectively known as shortwave radiation.

Solar radiation travels through space and passes through the atmosphere that surrounds the Earth, before reaching the surface of the Earth. While passing through the atmosphere, it interacts with different components of atmosphere in different ways. These interactions are discussed in the following section.

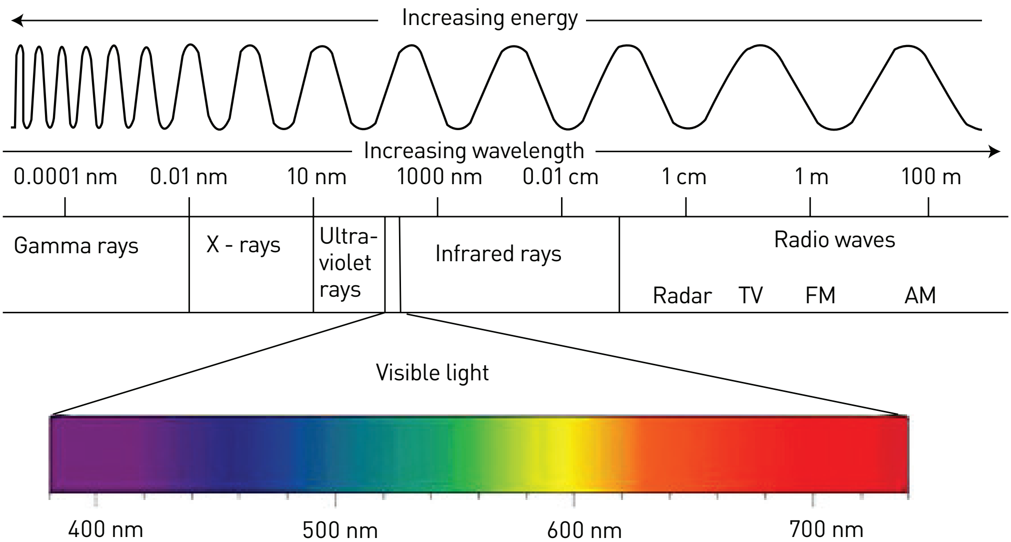


Fig. 1. Electromagnetic spectrum (EMS)

Interactions of Incoming Solar Radiation with the Atmosphere

Every planet has a characteristic composition of atmosphere. The major constituents of Earth's atmosphere are nitrogen (~78%), oxygen (~21%), argon (~0.9%), carbon dioxide (~0.04%) and water vapour (ranging from 0.2% to 4%, varying significantly with atmospheric temperature and pressure). The flow of energy between the Sun and Earth is influenced by a number of factors including the presence of clouds, humidity, properties of the gases and particles in the atmosphere. As the incoming solar radiation travels through the atmosphere, it may interact with different components of the atmosphere or pass directly to the surface of the earth. Depending upon the properties of atmospheric particles, different regions of the EMS are scattered, absorbed, reflected or transmitted. Atmospheric interactions such as absorption result in modification of incoming solar radiation.

(i) Scattering

When radiation from the Sun strikes small particles or gas molecules in the atmosphere, the incoming radiation deviates from its path or is scattered in random directions. This process, known as scattering, occurs without causing any change in the wavelength of the EMR (Fig. 2). A large fraction of the scattered radiation is directed back to space, which reduces the amount of incoming radiation reaching the surface of earth. Visible light is scattered in varying degrees by cloud droplets, gases such as oxygen and nitrogen, and dust particles. Cloud droplets being larger in size scatter all wavelengths of visible light, creating the white appearance of clouds. Oxygen and nitrogen, being much smaller in size than the wavelength of incoming radiation, scatter blue light of shorter wavelength, which makes the sky appear blue in colour.

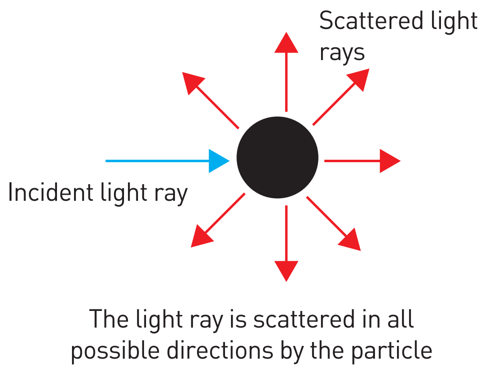


Fig. 2. Scattering of solar radiation

(ii) Absorption by atmosphere

Certain atmospheric particles have the ability to take up or absorb photons of incoming solar radiation. Atmospheric absorption mainly takes place at UV and IR wavelengths of the incoming radiation. Ozone present in the upper layers (stratosphere) of atmosphere is responsible for absorption of a significant amount of UV wavelengths of the solar radiation. The absorbed UV radiation is re-emitted by ozone molecules as thermal radiation in the IR region. Water vapour present in the lower region of atmosphere absorbs incoming radiation, particularly in the IR region of the EMS. Clouds and aerosol particles, such as black carbon also interact with and absorb some of this radiation.

(iii) Reflection by atmosphere

A small part of incoming radiation, which is not absorbed by the atmospheric particles,

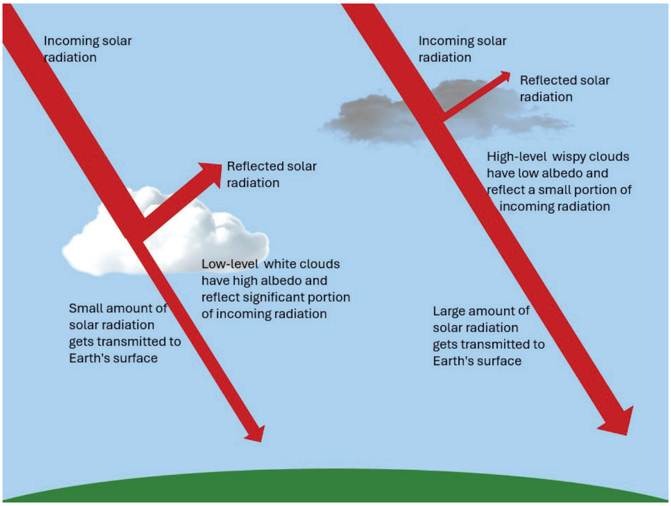


Fig. 3. Reflection of solar radiation and albedo

bounces back into space. This process, known as reflection, occurs without the transformation of energy into heat. The fraction of sunlight reflected by a surface is known as albedo. A surface that reflects large percentage of incoming solar radiation is said to have a high albedo.

Thin clouds found in the upper atmosphere reflect less light (low albedo), transmitting a significant portion of incoming radiation to the earth's surface. Clouds present in earth's lower atmosphere are thicker and thus, reflect a significant amount of the incoming solar radiation (high albedo) preventing it from reaching the earth's surface during the day (Fig. 3). Some large aerosol particles in the atmosphere also reflect solar radiation.

(iv) Transmission through atmosphere

A significant portion of incoming solar radiation does not interact with the atmosphere and is transmitted or passed down through the atmosphere without any changes.

(v) Reflection by the Earth's surface

A small portion of incoming solar radiation that is not absorbed by the surface of the Earth and is reflected back into the space. The amount of incoming radiation reflected by earth is dependent upon the features of land and water surfaces. Certain surfaces, such as snow, ice and sand have a high albedo thereby, reflecting larger amount of light back into the space. For example, sea ice reflects a large amount of incoming solar radiation and has a high albedo, melting of sea ice exposes darker sea surface, which has a low albedo.

(vi) Absorption by the Earth

About half of the total incoming solar radiation is absorbed by the surface of the earth. Earth's surfaces, especially those that are darker in colour, are better at absorbing solar radiation than air. The absorbed solar radiation by the earth's surface is converted into thermal energy. This energy is then transferred to the atmosphere through the processes of radiation, conduction and latent heat transfer.

Transfer of Energy from the Earth's Surface

The thermal energy from the earth's surface can be transferred to the atmosphere in three different ways.

(i) Radiation or radiant heat

As earth absorbs incoming solar radiation, the temperature of the surface of the earth increases. Earth emits radiation, which falls in the IR region and has electromagnetic waves of greater wavelength and lower energy than the incoming solar radiation (Fig. 4).

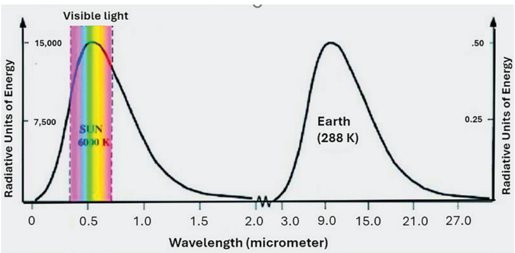
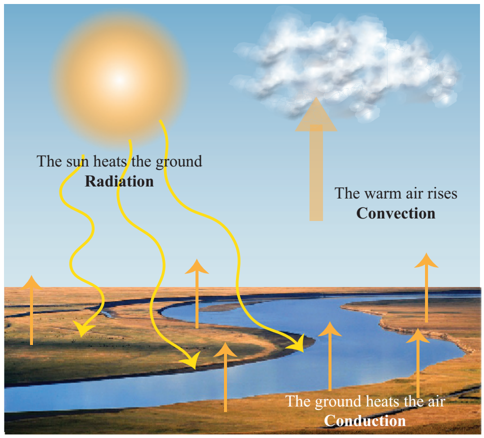


Fig. 4. Spectrum of incoming solar radiation and re-emitted radiation by earth's surface

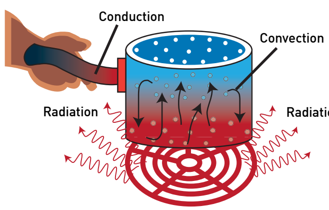
This long wave IR radiation re-emitted by the earth causes the surrounding temperature to increase. Though, earth receives solar radiation only during day hours, it emits IR radiation during both day and night. The IR radiation re-emitted by the earth causes the temperature of the surrounding to increase. There is a conversion from a range of incoming radiation to thermal IR. This thermal IR is what we experience as heat. Some of this radiated energy dissipates into space but a significant amount of heat is absorbed by the atmosphere.

(ii) Conduction

When the surface of land warms up by absorption of incoming radiation, it transfers heat to the overlying air through conduction. The heated air becomes less dense and rises. As the warm air ascends, it expands, cools down and eventually sinks back, setting up a convection current. This process contributes to the movement of heat through the atmosphere. The transfer of heat through the process of radiation, conduction and convection, that occurs in the atmosphere (Fig. 5a) is also something that we experience in everyday life as depicted in Fig. 5b.



(a) In atmosphere



(b) In daily life

Fig. 5. Radiation, conduction and convection

(iii) Latent heat transfer

Heat from the earth's surface is also transferred to the atmosphere when water from a land surface or water body evaporates. When water evaporates, it takes in heat from the surface (latent heat), which is needed to change phase from liquid to vapour. As the water vapour moves further away from the surface of the earth, it condenses to form water or ice crystals. This process of phase change then discharges heat into the atmosphere (for detail, see Box 2).

As the air warms due to the transfer of heat energy from the earth's surface, several interactions occur in the atmosphere which are discussed in the following section.

Interactions in the Atmosphere

The IR radiation emitted by earth's surface does not freely escape into space. It interacts with the atmospheric gases and clouds.

(i) Absorption of re-emitted radiation

Certain gases in the earth's atmosphere, such as carbon dioxide, water vapour and methane interact with and absorb the outgoing IR radiation emitted by the earth. These gases are called Greenhouse gases (GHGs).

Every vibrating body displays a property called frequency, which is a measure of the rate at which a vibrating body completes full cycle of motion. Molecules or bonds also vibrate with a set frequency called the frequency of vibration. A molecule with different kinds of atoms or more than two atoms can vibrate in multiple, more complex ways. When a molecule is hit by a radiation with a frequency that matches its natural frequency of vibration, the amplitude (maximum displacement from a mean position) of molecular vibration increases.

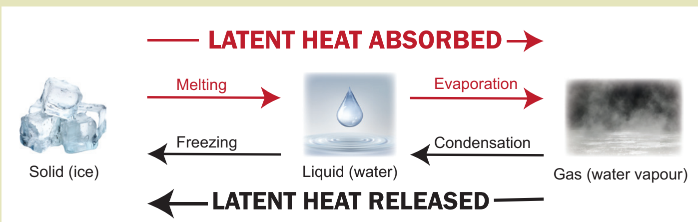
As the molecules vibrate, there is a change in charge distribution or dipole moment of the molecule (dipole moment fluctuates in sync with vibration of the molecule) (for detail, see Box 3).

Absorption of photon from IR radiation occurs and absorbed IR radiation is converted into the energy of vibration, further increasing the vibrations of the molecule. The molecule now undergoes relaxation to attain its original state.

For example, a CO_2 molecule can undergo four different types of vibration (Fig. 6). When exposed to IR radiation that matches its

Box 2: Latent heat

Heat is released or absorbed when water moves between solid, liquid and vapour forms. The heat required to change the phase of a substance while keeping the temperature of the substance constant is termed as latent heat. Heat is released when water vapour condenses or freezes, while heat is absorbed when ice melts or evaporates.



Box 3: Dipole moment

In some molecules, the electrons are not evenly shared between atoms. One end of the molecule may have a slight negative charge, while the other end has a slight positive charge. The difference in charges creates what we call a dipole moment. It is dependent upon the ability of an atom to attract electron towards itself (electronegativity). Certain vibrations in a molecule such as asymmetrical stretch and bending can bring about a change in their dipole moment. For example, in water (H_2O), the bond dipole moment arises due to the difference in electronegativity between hydrogen and oxygen. In case of carbon dioxide (CO_2), the net dipole moment is zero. This is because of linear and symmetrical geometry of the CO_2 molecule, the bond dipole moments cancel out each other. However, CO_2 can obtain a dipole moment on undergoing an asymmetrical stretch. Also, in case of molecules with same kind of atoms such as O_2 and N_2, the dipole moment is zero.

frequency of vibration, the molecule vibrates more vigorously. When CO_2 undergoes an

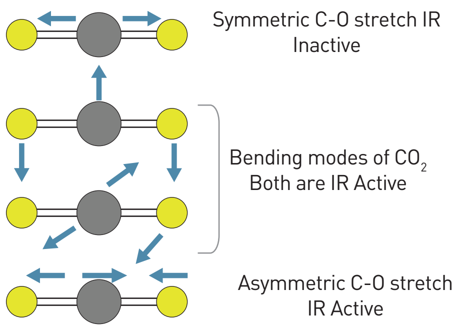


Fig. 6. Types of vibrations in CO_2

asymmetric stretch or bending, there is a change in its dipole moment, resulting in the absorption of photon from that IR radiation. Absorption of photon leads to more vigorous vibration and energy from photon is used for extra movement.

There are two ways that CO_2 can return to its normal resting state. It can collide with other air molecules, such as N_2 or O_2 and make them vibrate faster (transfer of kinetic energy) leading to the distribution of energy into air or it can release an IR photon after absorbing photon from incident radiation. When a photon is emitted, the molecule loses energy in that vibration and energy is transferred to the photon. Once CO_2 has transferred energy by any of the above mechanisms, it gets back to its resting state ready to absorb another IR photon and the cycle continues. This radiation re-emitted by the molecule can be directed back towards earth's surface or be absorbed by other greenhouse gases or atmospheric particles (Fig. 7). If the carbon dioxide molecule is at a high enough altitude, some small amount of IR radiation can also escape into space.

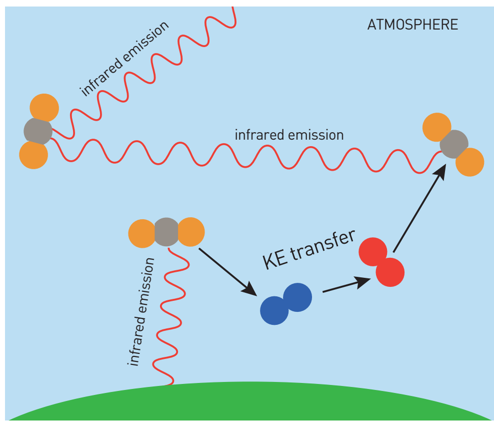


Fig. 7. Radiation re-emitted by molecules

Just like CO_2 other greenhouse gases in earth's atmosphere absorb IR radiation, which prevents its direct escape into space. This leads to retention or entrapment of heat in the earth's lower atmosphere, thereby raising the surface temperature of the earth and this process is known as the Greenhouse Effect. It is due to the greenhouse effect that the earth maintains a temperature suitable for life. However, human activities have intensified this natural process, contributing to global warming. The earth's surface receives twice as much radiation due to the greenhouse effect than it gets directly in the form of incoming radiation from the Sun.

Clouds in the lower atmosphere can absorb this radiation from the earth's surface and re-emit it, directing a portion back towards the earth. Thus, by trapping heat, clouds also have the ability to affect earth's energy balance.

(ii) Atmospheric window and escape into space

The wavelength of IR radiations emitted by the earth falls in the range of 5 to 100 μm. However, not all IR radiations emitted by the earth get absorbed by atmospheric gases. The atmosphere is transmissive (transparent) to specific wavelengths of IR radiations falling in the range of 7.8 to 15.3 μm. This range of electromagnetic radiation, which freely escapes through the earth's atmosphere without absorption is called the IR atmospheric window. While, gases naturally present in the atmosphere do not absorb in this atmospheric window, human-made gases such as Chlorofluorocarbons (CFCs) when added to the atmosphere absorb radiation falling in the atmospheric window, thereby enhancing greenhouse effect.

The reason why gases, such as nitrogen or argon, which are abundantly present in the atmosphere, do not absorb IR radiation is provided in Box 4.

(iii) Relationship between the concentration of greenhouse gases and global temperature

As a result of the presence of atmosphere consisting of greenhouse gases, the average global temperature on the surface of the earth is around 14°C. This makes the earth habitable for different life forms. In the absence of the atmosphere, the average global temperature on the surface of the earth would be around –18°C.

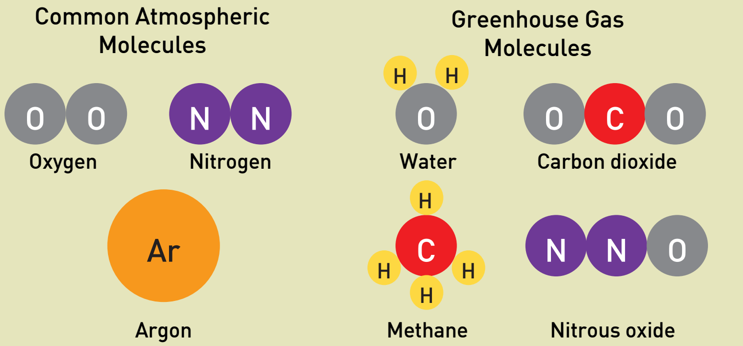
The sources and sinks of a greenhouse gas help to regulate its concentration in the atmosphere. For example, CO_2 is released from various sources such as industries, vehicular emissions and volcanic eruptions. Oceans, plants and soil form important sinks that take up CO_2 from air. The balance between sources and sinks helps regulate the concentration of carbon dioxide in the atmosphere.

Since the industrial revolution, human interference has heightened the natural greenhouse effect. Various anthropogenic causes, such as fossil fuel burning, cement production and deforestation have led to a rapid increase in the atmospheric concentration of greenhouse gases. As the concentration of GHGs increases, the amount of IR absorbed as well as radiation re-emitted by GHGs in the atmosphere increases.

It is important to note that some GHGs have a greater capacity for absorbing IR radiation or occur in significant quantities, whereas others have considerably lower capacities for absorption or occur only in trace amounts. The strength of greenhouse effect exhibited by different GHGs depends upon their molecular structure, relative concentration, lifetime in the atmosphere and the wavelength of radiation that they absorb (or radiative efficiency). A more detailed information is provided in Box 5.

Earth absorbs incoming solar radiation and in turn, re-emits longwave IR radiation. The presence of GHGs in the atmosphere leads

Box 4: Why do nitrogen and oxygen not absorb IR?



These are stable, symmetric molecules. They are not disrupted by lower energy IR radiation. The highest energy radiation from the sun will convert oxygen into ozone (O_3).

These are more complicated molecules. They can stretch, bend and otherwise, change shape in the presence of IR radiation. As they vibrate that way, they absorb and then emit radiation.

Molecules interact with only a certain range of wavelengths. Nitrogen and oxygen, which primarily make the Earth's atmosphere, do not absorb IR radiation in the same way that many other GHGs do. O_2 and N_2 molecules have identical atoms, which can only move closer (compression) or further apart (stretching). A symmetrical linear structure and strong triple bond leads to a very limited vibrational and rotational motion of the molecule, which does not readily match the frequencies of IR radiation. This limited vibrational motion does not change the charge distribution of the molecule, which is the reason why it does not absorb IR radiation.

Methane (CH_4) is another greenhouse gas, which has a symmetrical structure and no permanent dipole moment. But it can vibrate in ways that change its dipole moment allowing it to absorb IR radiation.

to the absorption of some amount of this outgoing radiation, preventing it from freely escaping to space.

As we go higher in the troposphere, the concentration of GHGs decreases. At certain altitude, the concentration of GHGs is low enough for the re-emitted radiation to make its way to outer space (rather than being reabsorbed or bounced around by other gas molecules). However, anthropogenic activities in recent years have led to an increase in the concentration of GHGs, which are now present at a higher atmospheric altitude than before. Consequently, IR radiation now escapes from this higher altitude, where the temperature is lower, leading to a reduction in the amount of IR radiation lost to space. This is because the temperature drops in the troposphere with altitude. A lower temperature results in corresponding

Box 5: What determines the strength of greenhouse effect of different gases?

Greenhouse gases vary in their capacity to contribute to the greenhouse effect. Some GHGs display a greater capacity for absorbing IR radiation, whereas others have considerably lower absorption capacities. The atmospheric concentration of different greenhouse gases also differs greatly.

The strength of greenhouse effect exhibited by different GHGs can vary depending upon their molecular structure, relative concentration, lifetime in the atmosphere and the wavelength of radiation that they absorb. The strength of greenhouse gases can also be measured in terms of their Global Warming Potential (GWP), which is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2).

The presence of oxygen and UV radiation make the atmosphere a very oxidative environment. Carbon dioxide does not react with atmospheric oxygen, allowing it to persist in the atmosphere for a very long time. Some CO_2 is taken up by the plants, oceans and soil, while the rest stays in the atmosphere from anywhere from a few hundred to thousands of years. CO_2 has a low heat-trapping ability compared to other greenhouse gases but its increased atmospheric concentration largely contributes towards enhanced greenhouse effect.

Methane (CH_4), on the other hand, readily reacts with oxygen in the atmosphere and converts into carbon dioxide and water. This reaction decreases the atmospheric lifetime of methane to around 12 years.

Water vapour (H_2O) is an effective greenhouse gas, capable of absorbing and re-emitting IR radiation at a wide variety of wavelengths. But it has negligible role towards anthropogenic greenhouse effect. As the average temperature of the earth increases due to increased greenhouse effect, there is greater evaporation of water from the earth's surface. Warmer air being able to hold more water vapour increases the concentration of water vapour in air. This water vapour then absorbs a wide range of IR radiation emitted by the earth and prevents it from escaping into space. A molecule of water vapour has an atmospheric life of just nine days. It then gets recycled as rain or snow.

Human-made fluorinated gases, such as CFCs (Chlorofluorocarbons) and SF_6 (Sulphur hexafluoride) are the longest lasting greenhouse gases in the atmosphere, with an atmospheric life of 2600 to 50,000 years. They are removed from the atmosphere only when they are destroyed by sunlight in the upper atmosphere. Fluorinated gases absorb IR radiation in the atmospheric window very efficiently. These gases have the highest GWP. The presence of Fluorine atoms in such gases create a larger separation of electric charge within the molecule and this helps the molecular bonds absorb IR radiation more effectively.

decrease in emitted radiation (recall the relation between emission and temperature of an object, Box 1). There is an overall decrease in the amount of outgoing energy compared to the amount of incoming energy. This results in increased heating of the earth's surface, making it warmer as a result of the enhanced greenhouse effect.

As mentioned in the beginning of the article, global warming occurs because less radiation goes out compared to the incoming solar radiation. This results in an increase in the global surface temperature. This means that the lesser the outgoing radiation, the higher the average global temperature on the surface of the earth will be. This is exactly what we are experiencing today. Earth, as a warmer object, now responds by emitting more radiation than before. This consequent increase in the average global temperature is what we commonly know as global warming, which today is a little more than 15°C. This temperature increase of even a little more than 1°C is accompanied by major climatic changes, such as the accelerated rate of melting of sea ice, glaciers and ice sheets, more intense weather events, etc. Therefore, global initiatives are undertaken to limit such increase of temperature. The Intergovernmental Panel on Climate Change (IPCC) at regular interval, prepares assessment reports to inform the world about the facts and findings related to climate change while also providing directions on the measures that can be taken.

IPCC's Fifth Assessment Report provided the scientific input into the Paris Agreement. This Agreement aims to strengthen the global response to the threat of climate change by holding the increase in the global average temperature to well below 2°C above preindustrial levels (global temperature during the period 1850–1900[2]). Further, it also recommended the efforts should be put in to limit the temperature increase to 1.5°C above preindustrial levels (Intergovernmental Panel on Climate Change, 2018).

If the concentration of greenhouse gases stabilises, then Earth's climate will once again come into equilibrium. However, the global average surface temperature would then be at a higher temperature than it was before.

Overall Energy Balance

We have discussed earlier how earth's energy balance is disrupted at various points as solar radiation interacts with different gases, clouds, snow, ice, etc. (Fig. 8). The overall effect of the gamut of interactions is that the outgoing radiant energy to space is less than the incoming solar radiation. This energy imbalance is balanced out by the increase in temperature on the surface of the earth and the atmosphere. Therefore, more greenhouse gases are released into the atmosphere and there will be lesser outgoing radiant energy to space. This will be accompanied by further increase in the temperature on the surface of the earth and in the lower atmosphere.

Summary

As we have seen, several processes, interactions and events are responsible for leading to global warming. The major processes, interactions and events that are

[2] https://www.ipcc.ch/site/assets/uploads/sites/2/2018/12/SR15_FAQ_Low_Res.pdf (Accessed March 27, 2024)

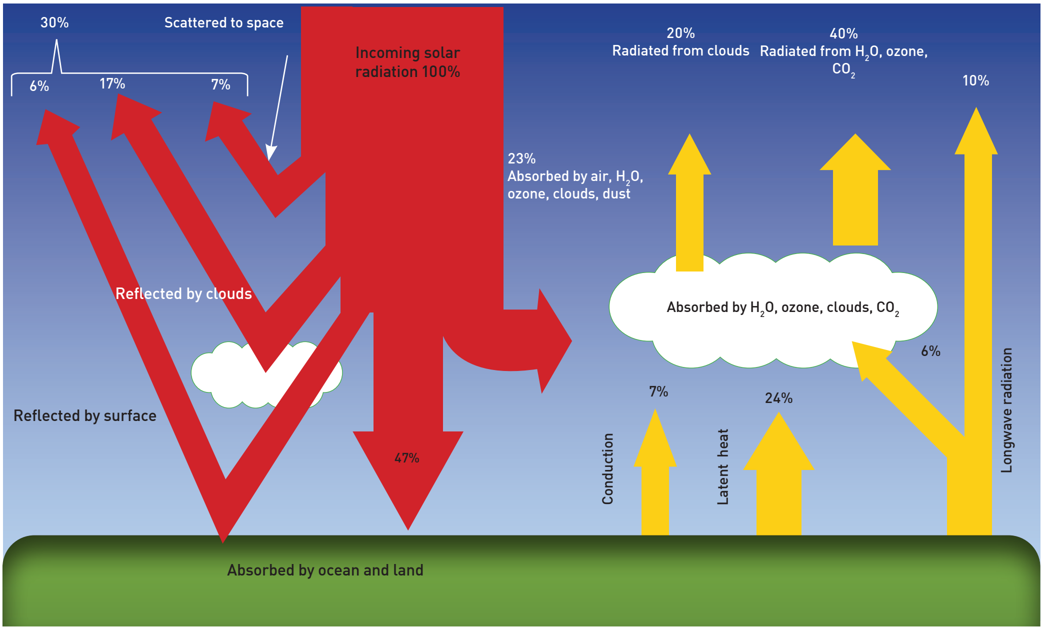


Fig. 8. Interactions of solar radiation

(% indicates approximate amount of solar radiation transferred in different forms)

linked with global warming are depicted in the infographic (Fig. 9). Although, they have been numbered, it is to be noted that all the events happen simultaneously and continuously.

Limitations and Direction for Future Research and Development

The paper focused only on the relevant concepts associated with global warming. It does not provide any guidance or direction for the associated pedagogy for transaction, which will be helpful for teachers. It also does not specify the specific grade in which the concepts may be included, which will be useful for curriculum developers. Future work may focus on these aspects. Considering the enormous volumes of resources available online, future work may also consider sifting of authentic resources, which will enhance teaching-learning about different concepts mentioned in the paper.

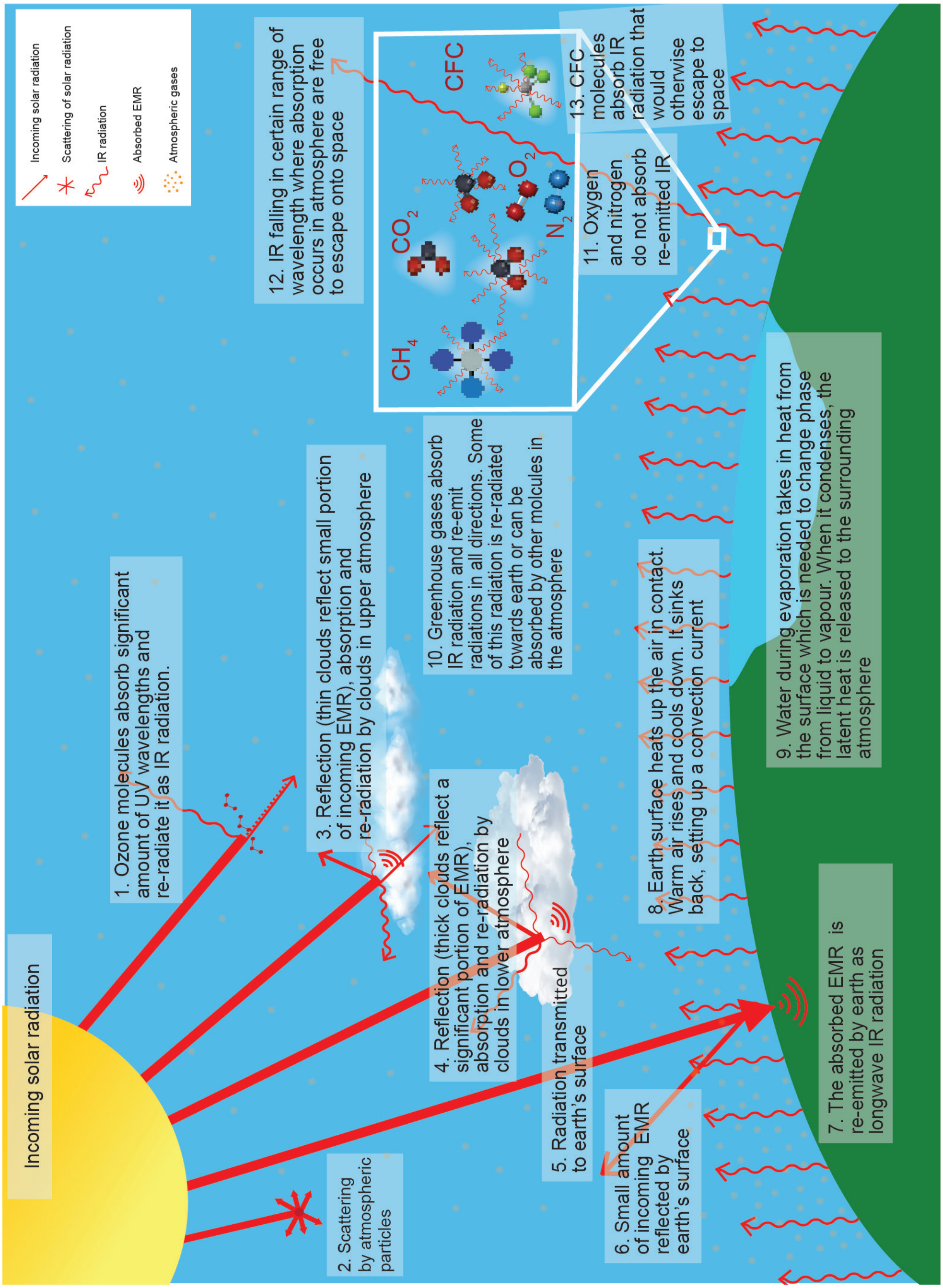


Fig. 9. Solar radiation dynamics

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