CHAPTER 5

PHYSICS AND ENVIRONMENT

It has been said long ago: "What benifits the man if he gains the whole world and looses his soul"

And now, I add: "What benifits the man if he exploits all modern technology and looses the world in which he lives"

A. PHYSICS AND ENVIRONMENT

A.1. Introduction

The widespread pollution on the whole globe motivated UNESCO to take part and coordinate scientific research in the fields responsible for pollution which affects drastically the global climate change. UNESCO also finds it very important to address climate change with educational programmes. In order to understand and develop reliable predictive models of climate change we have to start from the very beginning in our schools to instruct the student besides the information he takes, about the after effects and the dangers of this excessive use of modern technology. Typical problems in this respect are the greenhouse effect, the ozone layer problem and the increase in nuclear radiations in the Earth's atmosphere.

A.2. Climate change at different eras

The comparative values for atmospheric concentrations of CO_2 and temperature over the past 160,000 years show that they tended to go up and down together. At early times when the total population of mankind was about one million, the concentration of carbon dioxide in the atmosphere was not influenced by humans even though they had mastered the use of fire. Around 20,000 B.C. the temperature started to warm and the CO_2 concentration and the Earth's population started to increase. After agriculture started around 8,000 B.C. and agriculture replaced hunting and gathering, CO_2 rose further. The clearing of forests to allow for agriculture explained the increase in CO_2 concentration during this period. This in turn contributed to the rise in the global mean temperature since CO_2 is the principal greenhouse gas.

During the last century, the excessive burning of fossil fuels and the industrial revolution caused the atmospheric CO_2 concentration to increase by 25% from 280 parts per million by volume to the current value of 353 part per million by volume. The global temperature has

risen almost one degree Celsius during this period, and the population has risen from a figure below one billion to the current 5.5 billion. The industrial countries are responsible for the growing of the industrial CO_2 gas, at least 83% of the total output from all countries.

At present, it is well known that there exists a direct impact of modern technology and industrialization on the climate change of the globe. The seriousness of this problem makes it a matter of life and death for the whole globe and biosphere. Thus it is worthwhile to introduce to our students information about such problems during their educational periods.

A.3. Greenhouse gases and the absorption of infrared

Nitrogen, oxygen and argon form the major constituent gases in the Earth's atmosphere. Besides, we have small proportions of other gases such as carbon dioxide (CO_2), methane (CH_4), nitrogen dioxide (NO_2) and steam. The molecules of these gases are capable of absorbing long wave or infrared radiation. It is this inherent property of their structure that makes them **greenhouse gases**, since their natural concentration in the atmosphere means that not all the solar radiation reaching the planet is returned to outer space, but is held back. This blocking of part of the radiation (infrared) and its reflection back towards the surface of the Earth is what is known as **greenhouse effect**. This effect makes the temperature on the Earth suitable for life.

Human activities and the industrialization of many parts of the planet release almost 6,000 million tons of CO_2 into the atmosphere, along with hundreds of millions of tons of other greenhouse gases, such as methane and chloro-fluoro-carbonates, so that their presence in the atmosphere is increased massively. Forest fires also contribute considerably to the emission of greenhouse gases, Fig. 5.1.

Once released in the atmosphere, CO_2 remains there for a period of between 50 and 200 years. CH_4 , on the other hand, remains only for about 10 years, but can absorb between 20 and 30 times as much heat as CO_2 . All this makes the temperature of the Earth's crust increase above the limits of the natural variations. It has been shown

that the average global temperature of the Earth's surface has increased by 0.5 degrees in the last 100 years.

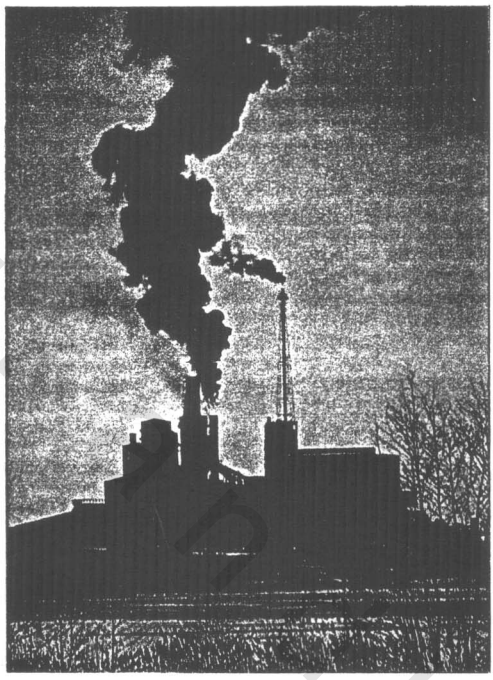


Fig. 5.1. The industrial emissions, main source of increase of the CO_2 atmospheric concentrations.

The estimated contribution to the increase of the Earth's temperature by different sources of emissions are as follows:

50% from energy sources (including transport),
20% from chemical products,
15% from tropical deforestation, and
15% from agriculture and refuse.

If we cannot control the emission of greenhouse gases, and they continue increasing at their current rate, then by the middle of the next century the temperature could reach the highest level in the last 20,000 years. This could have an unsettling effect on the climate of our planet.

Avoid it !

In order to avoid this serious change in climate, it is important to reduce the amount of coal, oil and natural gas we burn. It is also important to burn these substances as efficiently as possible.

A large portion of the energy consumed in the world today is not used to provide services from energy, but is simply degraded in the form of non-usable heat.

A.4. The study of gases in the Earth's atmosphere

A.4.1. The kinetic theory of gases

In solids the molecules are fixed in their positions under strong mutual attractions. When the temperature is raised until the melting point is reached, the structure breaks down giving a liquid. In a liquid molecules are more free to move at random though they are still held together in a body of fixed volume by molecular attractions. At the boiling point of a liquid the heat energy supplied as latent heat is sufficient to let free all molecules thus changing the liquid state to gaseous state. In gases the molecules occupy no fixed positions in space, and so a gas occupies the whole volume of the vessel in which it is placed.

In the following section we try to study the properties of the gas forming our atmosphere around the Earth.

One cubic centimeter of air contains about 2.7×10^{19} molecules. It is quite impossible to give the macroscopic properties of air in terms of a microscopic description involving the individual positions and velocities of this huge number of gas molecules. We must be content with a macroscopic description involving just a few variables that characterize the average conditions in the volume of gas. Parameters characterizing the average condition of a gas are the number of moles, the volume, the density, the pressure and the temperature. The kinetic theory attempts to derive relations between these macroscopic parameters and microscopic parameters characterizing individual molecules in a microscopic model of an ideal gas.

A.4.2. The ideal gas

In order to develop a microscopic model of an ideal gas we have to assume the following properties:

1. Gas molecules behave as hard, smooth and perfectly elastic spheres.
2. The molecules obey Newton's laws of motion, but the individual molecules move in a random fashion.
3. The average kinetic energy of the molecules is proportional to the absolute temperature, energy and momentum are conserved.
4. Intermolecular forces do not exist.
5. The number of molecules is large and the separation between them is large compared with their dimensions.

A.4.3. Calculation of kinetic pressure of a perfect gas

Let an amount of gas be enclosed in a three dimensional space xyz. Let dS be an element of area of the wall of the vessel perpendicular to the x-direction (see Fig. 5.2). Let us divide the molecules of the gas into groups 1,2,3, ...,i such that the number of molecules per unit volume in group i is n_i and the velocity components in the x,y,z directions are u_i , v_i , w_i , respectively.

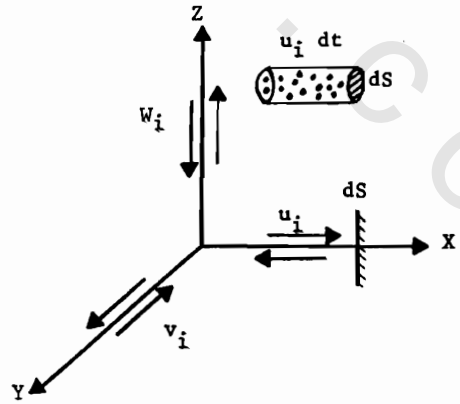


Fig. 5.2

Consider the molecules in the i^{th} group that travel in the x-direction with velocity u_i . The number of such molecules which will strike the element dS in time dt is the number contained in a cylinder of height (u_i dt) and basal area dS. This cylinder has a volume (u_i dt dS). The number of molecules per c.c. in this volume is (n_i u_i dt dS). The momentum of each molecule is (mu_i) where m is the mass of the molecule.

The total momentum of the whole number of molecules in this cylinder is $mu_i \times n_i u_i \, dt \, dS = m \, n_i \, u_i^2 \, dt \, dS$.

Summing up for all similar groups, then the total amount of momentum for all groups in a direction perpendicular to dS is

$$m \sum_i n_i u_i^2 \, dt \, dS \qquad i = 1,2,3, \ldots$$

Since one half of the molecules move in the positive direction while the other half moves in the negative direction, then:

The total momentum in the positive direction $= \frac{1}{2} m \, n \, u^2 \, dt \, dS$

where n is the total number of molecules per unit volume and u^2 is the mean square of the velocity components parallel to the x direction of all molecules, i.e.,

$$u^2 = [n_1 u_1^2 + n_2 u_2^2 + \ldots] / [n_1 + n_2 + \ldots]$$

$$= \sum_i n_i u_i^2 / \sum_i n_i$$

The total change of momentum after perfect elastic collision with the wall area dS is

$$2 \times \frac{1}{2} m \, n \, u^2 dt \, dS = m \, n \, u^2 \, dt \, dS$$

This is equal to the impulse of the force exerted by the molecules on dS in time dt.

Thus if P is the gas pressure (force per unit area) then the force exerted by the gas on dS is P dS .

$$\text{The impulse} = \text{force} \times \text{time} = p\, dS\, dt$$

$$m\, n\, u^2\, dt\, dS = P\, dS\, dt$$

Therefore: $$P = m\, n\, u^2$$

Generalizing this relation to include the molecular velocity in the 3-D space, we introduce the mean square velocity c:

$$c^2 = [n_1 c_1^2 + n_2 c_2^2 + \ldots] / [n_1 + n_2 + \ldots]$$

$$= \sum_i n_i\, c_i^2 \Big/ \sum_i n_i$$

where c_1 is the resultant of u_1 , v_1 , w_1 of group 1, etc, ..., also we have:

$$c^2 = u^2 + v^2 + w^2$$

Assuming: $$u^2 = v^2 = w^2$$

Then $$u^2 = \tfrac{1}{3} c^2$$

Therefore, $$P = \tfrac{1}{3} m\, n\, c^2$$

If we consider 1 g-molecule of a gas occupying a volume V, then we have:

$$P\, V = \tfrac{1}{3} m\, n\, c^2 = \tfrac{1}{3} m\, (N/V)\, c^2$$

where N is the number of molecules in a g-molecule and is called Avogadro's number. It has a value 6.02×10^{23} molecules per mole. Therefore,

$$p\, V = \tfrac{1}{3} m\, N\, c^2$$

Introducing the absolute temperature (T) we use the empirical relation:

$$P\, V = R\, T$$

where R is the gas constant. Therefore,

$$\frac{1}{3} m n c^2 = R T$$

$$\frac{1}{2}\left(\frac{2}{3}\right) m c^2 = (R/N) T = k T$$

where $k = R/N$, is called Boltzmann's constant and has a value of 1.38×10^{-16} erg/molecule deg. Since $1/2\ mc^2$ is the kinetic energy per molecule, therefore,

$$\frac{2}{3} \text{ kinetic energy per molecule } = k T \quad , \text{or}$$

The kinetic energy per molecule is $3/2\ kT$, and since for a perfect gas we only have three translational degrees of freedom, then:

$$\text{The kinetic energy per molecule per degree of freedom } = \frac{1}{2} k T .$$

This is known as the law of equipartition of energy. It states that in a dynamical system in thermal equilibrium, the energy is equally distributed between the various degrees of freedom and for each of them it is equal to $1/2\ kT$.

In one g-molecule of a gas we have Avogadro's number, N, of molecules, thus the energy of an ideal gas per mole is:

$$E = \frac{3}{2} N k T = \frac{3}{2} R T$$

If we have only a fraction n of mole, then,

$$E = \frac{3}{2} n R T$$

Example 5.1:

What is the thermal energy in 1 kg of He gas at 0 °C ? How much extra energy must be supplied to increase its temperature to 60 °C ? (Molecular weight of He = 4.0 g/mole).

Solution:

$$n = 1 \text{ kg} / 4.0 \text{ g/mole} = 250 \text{ moles}$$

$$E = \frac{3}{2} n R T = \frac{3}{2} \times 250 \times 8.3 \text{ J/K} \times 273 \text{ K} = 8.5 \times 10^5 \text{ J}$$

The extra energy is $= \frac{3}{2} n R \Delta T = 1.9 \times 10^5$ J

A.4.4. Heat capacity and energy stored in a gas

We have found that the temperature of a gas is a measure of the average translational kinetic energy of the molecules of a perfect gas. The kinetic energy is associated with the motion of the center of mass of each molecule. It does not include the energy associated with internal motion in real gas molecules, namely, vibrational and rotational degrees of freedom about the center of mass. This is quite evident since the simple kinetic theory model assumes a structureless molecule.

Considering the simplest case of an ideal monoatomic gas containing one atom per molecule, such as helium or argon, all of the kinetic energy of such molecules is associated with the motion of their centers of mass. Heating a monoatomic gas in a container of fixed volume will add energy as translational kinetic energy of the atoms. There is no other way to store energy in a monoatomic gas. Thus, the total internal energy U of N molecules (or n moles) of an ideal monoatomic gas is given by:

$$U = \frac{3}{2} N K T = \frac{3}{2} n R T$$

It is important to note that for an ideal gas (only), U is a function of T only.

If heat is transferred to the system at constant volume, no work ($W = \int P \, dV$) will be done by the system. Hence, from the first law of thermodynamics we see that:

$$dQ = dU = \frac{3}{2} n R T$$

In other words, all of the heat transferred goes into increasing the internal energy and temperature of the system. From the definition of specific heat:

$$dQ = C\,dT$$

Therefore, $$n\,C_V\,dT = \frac{3}{2}\,n\,R\,T$$

Then $$C_V = \frac{3}{2}\,R$$

This expression predicts a value of $C_V = 12.5$ J/mol.K for all monoatomic gases.

If heat is transferred to the system at constant pressure, and the temperature is increased by dT, then the heat that must be transferred to the gas in this process is given by:

$$Q = n\,C_P\,dT$$

where C_P is the molar heat capacity at constant pressure.

Since the volume increases in this process, work is done by the gas:

$$dW = P\,dV$$

Applying the first law to this process gives

$$dU = dQ - dW = n\,C_P\,dT - P\,dV$$

In this case, the heat added to the gas is transferred in two forms. Part of it is used to do external work and the remainder increases the internal energy of the gas. Since: $P\,V = n\,R\,T$, then for constant pressure

$$P\,dV = n\,R\,dT$$

Thus: $$dU = n\,C_V\,dT = n\,C_P\,dT - n\,R\,dT$$

Therefore, $$C_P - C_V = R$$

This expression applies to any ideal gas. Since $C_V = 3/2\ R$, for a monoatomic gas, then $C_P = 5/2\ R = 20.8$ J/mol.K .

The ratio of these heat capacities is a dimensionless quantity γ given by:

$$\gamma = C_P / C_V = 5/3 = 1.67$$

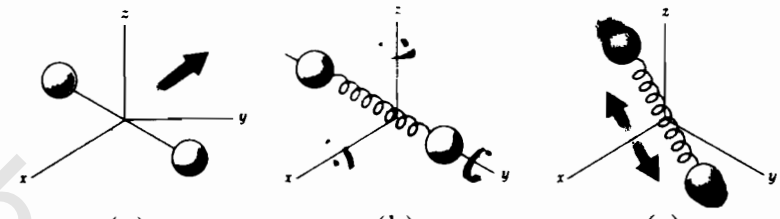
This value was found in excellent agreement with experimentally determined value for monoatomic gases.

In diatomic and polyatomic gases with molecules of complex structures we expect some additional contribution to the specific heat from the internal structure. The internal energy and hence the specific heat of a complex gas must include contributions from the rotational and vibrational motions of the molecule.

A.4.5. Origin of the specific heat

So far we have assumed that the sole contribution to the internal energy of a gas is the translational kinetic energy of the molecules. However, the internal energy of a gas actually includes contributions from the translational, vibrational and rotational motion of molecules. The rotational, vibrational motions of molecules with structure can be activated by collisions and therefore are coupled to the translational motion of the molecules. It has been shown by statistical mechanics that the available energy is, on the average, shared equally by each independent degree of freedom. Recall that the law of equipartition of energy assigns $1/2$ kT of energy per molecule.

Let us consider a diatomic gas, which we visualize as a dumbbell-shaped molecule (see Fig. 5.3). In this model, the center of mass of the molecule can translate in the x,y,z directions. In addition, the molecule can rotate about three mutually perpendicular axes, see Fig. 5.3b. We can neglect the rotation about the y-axis since the moment of inertia and the rotational energy, $1/2\ I\ W^2$, about this axis are negligible compared with those associated with the x and z axes.



(a) Translational (b) Rotational (c) Vibrational

Fig. 5.3. Possible motions of a diatomic molecule: (a) translational motion of the center of mass, (b) rotational motion about the various axes, and (c) vibrational motion along the molecular axis.

Thus, there are five degrees of freedom: three associated with translational motion and two associated with the rotational motion. Since each degree of freedom contributes $1/2$ kT of energy per molecule, the total energy for N molecules is:

$$U = 3N\left(\tfrac{1}{2} k T\right) + 2N\left(\tfrac{1}{2} k T\right) = \tfrac{5}{2} N k T = \tfrac{5}{2} n R T$$

Using this equation one finds that the molar heat capacity at constant volume is

$$C_V = \frac{1}{n}\frac{dU}{dT}$$

$$= \frac{1}{n}\frac{d}{dT}(5 n R T/2) = \frac{5}{2} R$$

And $$C_P = \frac{7}{2} R ;$$

therefore, $$\gamma = C_P / C_V = 1.4$$

The vibrational modes add two more degrees of freedom, corresponding to the kinetic and potential energies associated with vibrations along the bond length of the molecule.

For molecules with more than two atoms, the number of degrees of freedom is even larger and the vibrations are more complex. This results in an even higher predicted heat capacity. The following table gives molar heat capacities of some gases.

		Molar heat capacity (J/mol.K)		
		C_P	C_V	$\gamma = C_P / C_V$
Monoatomic	He	20.8	12.5	1.67
	Ar	20.8	12.5	1.67
Diatomic	H_2	28.8	20.4	1.41
	N_2	29.1	20.8	1.40
	O_2	29.4	21.1	1.40
Polyatomic	CO_2	37.0	28.5	1.30
	H_2O	35.4	27.0	1.30
	CH_4	35.5	27.1	1.31

A.4.6. Heat capacities of gases, liquids and solids

It has been shown that the elementary kinetic theory of gases requires that the specific heat of gases at constant volume should be $3/2$ R. The molar specific heats of a number of gases are given in the above table. Fig. 5.4 shows the temperature dependence of heat capacities of different gas molecules. It can be seen that only monoatomic gases satisfy the requirement. The specific heat of nitrogen and hydrogen, for instance, is about $5/2$ R at room temperature. Polyatomic gases have higher values of heat capacities particularly at larger temperatures.

The failure of the equipartition theorem to explain such differences in behavior is due to the inadequacy of classical mechanics when applied to molecular systems. For a more satisfactory description, it is necessary to use a quantum-mechanical model in which the energy of an individual molecule is quantized. The energy separation between rotational energy levels is small compared with the thermal agitation energy kT. Excitation of these modes of vibration are therefore possible at these temperatures. A diatomic molecule, like N_2 , has two rotational degrees of freedom corresponding to rotation around two mutually perpendicular axes. A

triatomic molecule, like CO_2 , can rotate around three mutually perpendicular axes. It is obvious that the higher the temperature the faster the molecules rotate and the more energy is stored. The increase in the stored energy leads naturally to an increase in the temperature of the gas.

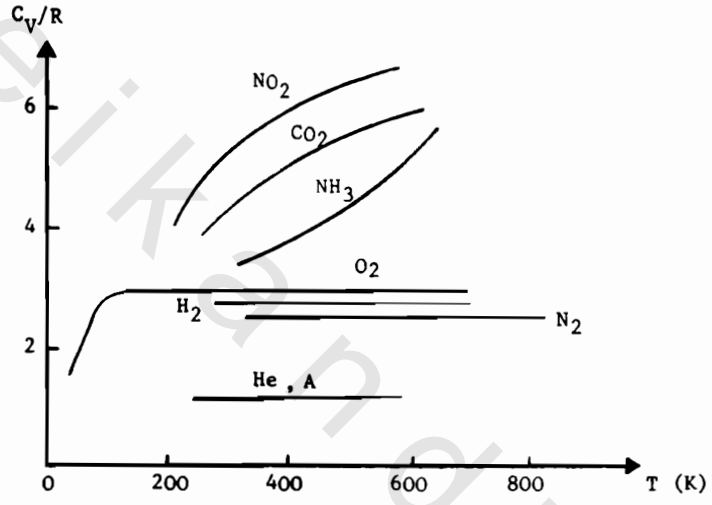


Fig. 5.4. The molar specific heats of a number of gases as a function of temperature. Polyatomic gases show large increase due to the excitation of rotational modes of vibration.

A.4.7. Heat capacity of solids

Measurements of heat capacities of solids show a marked temperature dependence, showing a decrease in a nonlinear manner approaching zero at the absolute zero of temperature. At high temperatures the heat capacity of solids approach the value 3R. This result was first predicted by Dulong-Petit.

The explanation of the constancy of the heat capacities of solids was based on the law of equipartition of energy derived from the kinetic theory of gases. The solid is formed of an array of atoms tightly bonded together with atomic bonds. For small displacements

of an atom from its equilibrium position, each atom executes simple harmonic motion in the x,y and z directions. The energy associated with vibrational motion in any one direction is given by

$$E = \frac{1}{2} m v^2 + \frac{1}{2} k x^2$$

Therefore, each atom of the solid has six degree of freedom, three kinetic and three potential. According to the equipartition theorem, this corresponds to an average energy of 6 ($1/2$ kT) = 3 kT per atom. For one gram molecule the total internal energy U is

$$U = 3 N k T = 3 R T$$

The specific heat is thus dU/dT

Therefore, $$C_V = 3 R$$

which is the empirical law of Dulong and Petit. The discrepancy of this model and the experimental data at low temperature is due to the inadequacy of classical physics in the microscopic world. When the quantization principle was applied to the atomic harmonic oscillator whose frequency varied on a frequency spectrum, the experimental curve shown in Fig. 5.5 fitted the theoretically calculated one according to Debey's theory of specific heats for solids.

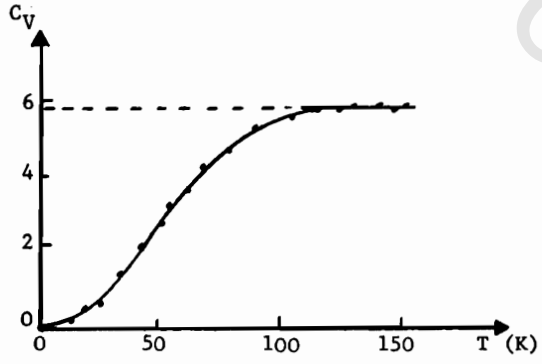


Fig. 5.5. Molar heat capacity as a function of temperature for Ag. The experimental points fitted well on the theoretical curve.

A.5. Atomizers and the chloro-fluoro-carbon gas

Perfume atomizers as well as those used for spraying pesticides at homes and for similar purposes, usually use chloro-fluoro-carbon gas to produce the required pressure over the fluid. This gas after being freed from the atomizers reacts with the ozone gas existing in the mesosphere thus demolishing the ozone layer in the atmosphere. The hole that is produced in the ozone layer allows intensive rays of ultraviolet to penetrate through the air and reach the Earth's surface. People exposed to such high intensity of ultraviolet radiations might endure severe harmful effects such as cancer skin. Small doses of this radiation are useful since it transforms some compounds in the human body to vitamin D, however, high doses are very dangerous.

A.5.1. Flow of liquids

In order to understand how an atomizer works we first consider the streamline flow of a liquid and the continuity equation. Consider a stream tube, Fig. 5.6, with variable cross sections. At the point A_1 the velocity of flow is v_1 and at the point A_2 the velocity of flow is v_2

Since the fluid is incompressible and moving in a stream line motion, the amount of fluid that passes by A_1 in time Δt is equal to the amount leaves the point A_2 in the same time. Since the fluid cannot accumulate in the tube between A_1 and A_2, hence:

$$v_1 A_1 \Delta t = v_2 A_2 \Delta t$$

Therefore:

$$v_1 A_1 = v_2 A_2$$

This relation is called the continuity equation, showing that the speed of flow is inversely proportional to the cross sectional area of the stream tube.

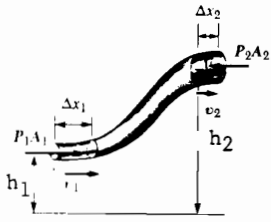


Fig. 5.6. A stream tube.

A.5.2. Bernoulli's equation

Consider the flow of an incompressible fluid through a considered pipe. The volume of the fluid passing any point per unit time is the same everywhere.

The force on the lower end of the fluid is $P_1 A_1$, where P_1 is the pressure at point 1. The work done by this force is

$$W_1 = F_1 \Delta x_1 = P_1 A_1 \Delta x_1 = P_1 \Delta V$$

where ΔV is the volume of fluid passing in unit time.

Similarly, the work done on the fluid at the upper end in unit time is given by

$$W_2 = - P_2 \Delta V$$

This work is negative since the fluid force opposes the displacement. The net work done by these forces per second is

$$W = (P_1 - P_2) \Delta V$$

Part of this work goes into changing the kinetic energy of the fluid, and part into changing the gravitational potential energy. If m is the mass passing through the pipe per unit time, then the change in kinetic energy is

$$\Delta(K.E.) = \frac{1}{2} m v_2^2 - \frac{1}{2} m v_1^2$$

The change in potential energy is

$$\Delta(P.E.) = m\,g\,h_2 - m\,g\,h_1$$

Since energy is conserved in the system of pipes, then:

$$(P_1 - P_2)\,\Delta V = \tfrac{1}{2} m\,v_2^2 - \tfrac{1}{2} m\,v_1^2 + m\,g\,h_2 - m\,g\,h_1$$

Dividing by the volume (ΔV) and knowing that the density (d) is given by $d = m/\Delta V$, the above expression reduces to:

$$P_1 - P_2 = \tfrac{1}{2} d\,v_2^2 - \tfrac{1}{2} d\,v_1^2 + d\,g\,h_2 - d\,g\,h_1$$

This equation is often expressed as

$$P + \tfrac{1}{2} d\,v^2 + d\,g\,h = \text{constant}$$

This is **Bernoulli's** equation stating that: "The sum of the pressure (P), the kinetic energy per unit volume ($1/2\ dv^2$), and the potential energy per unit volume (dgh) has the same value at all points along a stream line".

Special cases

1) When the fluid is at rest, $v_1 = v_2$, and Bernoulli's equation becomes:

$$P_1 - P_2 = d\,g\,(h_2 - h_1) = d\,g\,h$$

2) When the pipe is horizontal, $h_1 = h_2$, thus:

$$P_1 + \tfrac{1}{2} d\,v_1^2 = P_2 + \tfrac{1}{2} d\,v_2^2$$

From the equation of continuity: $A_1 v_1 = A_2 v_2$, thus:

$$P_1 + \frac{1}{2} d\,(A_1/A_2)\, v_2^2 = P_2 + \frac{1}{2} d\, v_2^2$$

Thus, the velocity of flow v_2 is given by

$$v_2^2 = A_1^2 \left(2(P_1 - P_2) / d\,(A_1^2 - A_2^2)\right)^{1/2}$$

This result shows that the pressure is reduced in the constricted part of the pipe. This explains the coagulation of blood in superficial wounds where the blood vessels are narrow is much easier than the wounds where veins or arteries are cut.

3.5.2. Applications of Bernoulli's equation

i. Stream line flow around an airplane wing:

The shape of airplane is designed such that the upper surface has a smaller radius of curvature than the lower surface, see Fig. 5.7. Air flowing over the upper surface follows more of a curved path than the air flowing over the lower surface. Since the direction of decreasing pressure is toward the center of curvature, the pressure is lower at the upper surface. The approaching air accelerates into this low pressure region; hence, the air speed is greater past the upper surface.

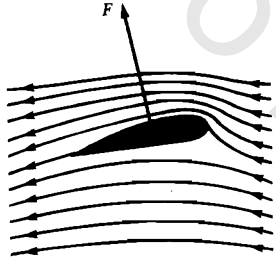


Fig. 5.7. Stream line flow around an airplane wing.

A net force, F, exists on the wing called **the dynamic lift.** This force depends on several factors, such as the speed of the airplane, the area of the wing, its curvature, and the angle between the wing and the horizontal.

ii. The atomizer:

When a stream of air is passed over an open tube the pressure is reduced above the tube. This reduction in pressure causes the liquid to rise into the air stream. The liquid is then dispersed into a fine spray of droplets. A number of devices operate in this manner, such as the atomizer used in perfume bottles and paint sprayers.

Figure 5.8 shows the design of a sprayer in which a stream of air passing over a tube dipped into the liquid will cause the liquid to rise in the tube as shown. The problem with these atomizers is that air is not used as the driving agent, but gases such as chloro-fluoro-carbon gas is usually used instead. This gas reacts with the ozone gas in the air atmosphere thus allowing intense ultraviolet rays from the Sun to reach the Earth's surface causing the hazards associated with what is called **the ozone layer problem.**

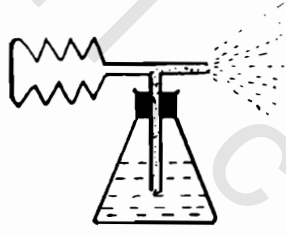


Fig. 5.8. The atomizer.

iii. Bernoulli's theorem and the human blood:

The blood vessels in the human being form a network of pipes of different cross sections. Besides, the blood moves in different parts of the body at different heights from the ground, i.e. the potential energy differs at different levels. An artery is a wide blood vessel in

which the blood pressure is high but the velocity of flow is low. If the artery is constricted as a result of an accumulation of plaque on its inner walls, then in order to maintain a constant flow rate through such a constricted artery, the driving pressure must increase. Such an increase in pressure requires a greater demand on the heart muscle. If the blood velocity is sufficiently high in the constricted region, the artery may collapse under external pressure, causing a momentary interruption in blood flow. At this point there is no Bernoulli's principle and the vessel reopens under arterial pressure. As the blood rushes through the constricted artery, the internal pressure drops and again the artery closes.

Such variations in blood flow can be heard with a stethoscope. If the plaque becomes dislodged and ends up in a smaller vessel that delivers blood to the heart, the person can suffer a heart attack.

A.6. Formation of atmospheric ozone hole

The Earth's atmosphere contains a large amount of free oxygen, which is created by the photosynthesis of plants. Oxygen has an important role in the control of life by making the respiration of animals and humans possible. It has another biospheric importance by the formation of ozone in the atmosphere between the heights of about 15 and 30 kilometers. This ozone layer absorbs the ultraviolet solar radiation which is harmful to different living species.

It was recently found that free radicals, e.g. hydroxil: OH, formed from atomic oxygen and water vapor, also, nitrogen oxides, and chlorine species contribute significantly to the depletion of the ozone layer in the stratosphere.

Under natural conditions nitrogen oxides, NO and NO_2 , in the stratosphere form from nitrous oxides N_2O . This gas, emitted into air by the microbiological activities of soils, is chemically inert in the troposphere, which is the air layer near the surface in which the temperature decreases. However, in the stratosphere it is disintegrated under the action of ultraviolet radiation to form nitrogen monoxide, NO, which reacts rapidly with ozone. The nitrogen dioxide, NO_2 , created in this way removes atomic oxygen from air:

$$NO + O_3 = NO_2 + O_2$$
$$NO_2 + O = NO + O_2$$

The net result is thus $O_3 + O = 2\,O_2$

These two reactions remove the majority of ozone molecules from the stratosphere. As it can be seen, nitrogen oxides re-form by the above reactions. This process could continue for ever if other species did not react with the nitrogen oxides, e.g.

$$NO_2 + OH = HNO_3$$

The ozone layer could also be modified by human activities. The supersonic aircraft flying in the stratosphere emit nitrogen oxides, and the fertilizers used by man can modify the nitrous oxide emissions of soils.

Much more dangerous are the chloro-fluoro-carbon, CFC's, gases, the Freon, used as refrigerants, propellants and solvents. These gases are inert in the troposphere but they are very reactive, like N_2O molecules, in the stratosphere. They are destructed under the effect of ultraviolet radiation to produce atomic chlorine, Cl, which reacts immediately with ozone as:

$$Cl + O_3 = ClO + O_2$$
$$ClO + O = Cl + O_2$$

The net result is thus $O_3 + O = 2\,O_2$

A.6.1. Explanation of the ozone hole

Results of experiments showed that at low temperatures ice crystals absorb hydrochloric acid, HCl, molecules. Subsequently, the ice absorbs also chlorine nitrate, $ClNO_3$, and in the solid ice the following reaction takes place:

$$ClNO_3 + HCl = Cl_2 + HNO_3(H_2O)$$

The chlorine, Cl_2 , formed in this way is liberated in gaseous form, while the nitric acid trihydrate, $HNO_3(H_2O)$, remains in the solid

phase. In other words active chlorine is liberated from two existing species.

The low temperatures necessary for this process are present in the stratosphere over the Antarctica during winter time. However, the ozone hole can be observed in spring since for photolysis of Cl_2 molecules solar radiation (ultraviolet) is needed. Two chlorine monoxide, ClO, produce one chlorine atom and one chlorine dioxide molecule:

$$(ClO)_2 + \text{U.V. photon, hf} = Cl + ClO_2$$

Laboratory studies showed that the process depends on the original concentration of chlorine species. Besides, the rate of reaction is a function of temperature: the lower the temperature the higher the probability of this reaction, which occurs essentially in ice crystals. This explains why a large depleted ozone layer is found on the polar regions.

Many scientists argue that the ozone hole is caused by halocarbons, CFC's gases, and freon, that is released by human activities. It is now evident that this ozone depletion should be stopped and prevented by a stop of the production and use of halocarbons. The problem should be solved internationally (Fig. 5.9).

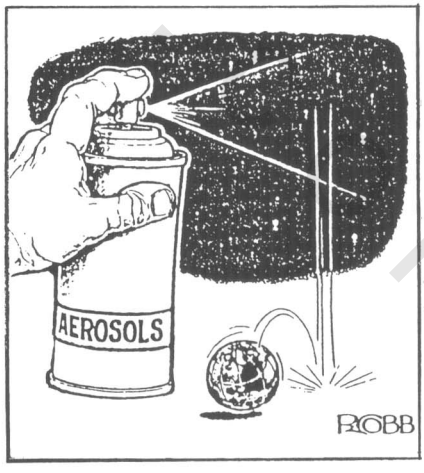


Fig. 5.9. Save our young generations by stopping the production of aerosols and CFC's gases.

A.7. The impact of science and technology on humanity

Modern physics teaches us that the processes of the universe are not simply mechanical motions of matter. It is more appropriate to look at them as the organization and transformation of energy. Energy is the ability to do work and so bring about change, it takes the form of motion and interactions. Accordingly, the universe is not made of things but it is made of interactions and change. All our contemporary problems have significant science and technology components. It could be easily seen how science and technology impacts on society, removing problems and bringing about other forms. For instance, because medical science has partly solved the problem of death disease, we now have the problem of overpopulation. The death problem has been replaced by a birth problem. Because we have accepted science's help in solving the death side of the birth-and-death equation but have not simultaneously taken responsibility for the birth side, we have burdened the planet with more people than it can handle.

Humankind is not paying its dues for the fruits of the scientific age. We are quick to accept the speed of the automobile, the fun of the television, and the cures of medicine, but we are slow to acquire good living habits, or to control our birth rate. The ozone problem is a good example. We enjoyed refrigerators in houses and air conditioning for many decades before anybody took the trouble to consider the effect of chloro-fluoro-carbon gases on the atmosphere. Earth, including our own health, is paying the price. We dare not accept science's benefits without accepting its responsibilities.

It is now becoming an urgent need for all, scientists and nonscientists, to learn more about the physical universe and our planet. Humankind is using great power today, without knowledge. If we want our technology-based society to succeed, we should reconsider what we are doing, for the use of power without knowledge is a prescription for disaster.

B. THE PHYSICS OF THE ATMOSPHERE

B.1. Structure of the Earth's natural atmosphere

The gas layer surrounding the Earth is called **the Earth's atmosphere.** The density of the gas in this layer decreases with height. The main constituents of the dry air are: nitrogen (N_2), 78%; argon (Ar), 0.93%; oxygen (O), 21%; and some other minor constituents representing only about 0.036% by volume of the homosphere. Carbon dioxide (CO_2) forms the most important and abundant gas of the minor constituents of air, 0.033% by volume. It arises from industrial and biological sources, but it is removed by green plants in photosynthesis, and by dissolving in water of oceans and rain.

B.1.1. The troposphere

It is the lowest layer of the atmosphere, in which the temperature decreases steadily with increasing altitude up to a height of 8 to 16 kilometers (km). The rate with which the temperature decreases with height is about 6.5 °C per km. At the top of this layer the temperature might reach -60 °C. Clouds, rain, lightning and most visible phenomena take place in the troposphere.

The variation of pressure with height could be obtained by considering an element of volume of the air (see Fig. 5.10) in equilibrium under two forces: (1) the gravitational force on the element of unit cross section and height dh = ρ g dh , and (2) the gradient of pressure force = dP .

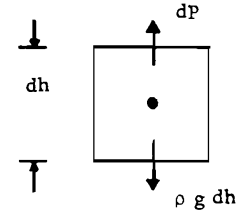


Fig. 5.10. Forces on an element of air volume at a height h and where the air pressure is P.

The hydrostatic equation is commonly written as

$$dP = -\rho g\, dh$$

In this equation, P is the pressure in Newtons per square meter, ρ is the density in kg/m^3 , g is the acceleration due to gravity in m/s^2 (= 9.8 m/s^2 at sea level), and h is the height in meters. The equation can be put in a more useful form by making use of the perfect gas law:

$$P\,V = R\,T$$

where V is the specific volume, R is the gas constant, and T is the absolute temperature. Putting R = N k, where N is Avogadro's number and k is Boltzmann's constant, then:

$$P = N\,k\,T/\,V = n\,k\,T$$

where n is the number of particles per cubic meter of air. Knowing that $\rho = n\ m$, where m is the molecular mass, then

$$P = \rho\,k\,T\,/\,m$$

and so:

$$\rho = P\,m\,/\,k\,T$$

Using the hydrostatic equation we get:

$$dP/P = -\,dh/H$$

where ($H = k\,T\,/\,m\,g$) is a constant. By integration we get the law of variation of pressure with height:

$$P = P_o \exp\,[-\,h/H]$$

P_o being the pressure at sea level.

Since the acceleration of gravity (g) is not constant but changes with height h according to

$$g(h) = g(0)\ r^2\,/\,(r + h)^2$$

h is the height above the level r corresponding to g(0).

Considering the variation of H with height we find a change in its value from 8.4 km at sea level to 60 km at an altitude of 300 km under average atmospheric conditions.

B.1.2. Winds and climate

Air circulation in the Earth's atmosphere is a complex subject. In the following section we give some brief remarks on wind and climate.

The surface of the Earth receives more solar radiation in equatorial regions than polar regions. A flow of air from low latitude to high latitude tends to redistribute and equalize the heat content of the atmosphere as a function of latitude. Without this flow the temperature difference between different parts on Earth would be much greater than it is. The air currents from low latitudes to high latitudes and the associated reverse currents are modified by the rotation of the Earth and the consequent Coriolis force, and by the presence of land masses and other factors. The overall result of all the factors affecting air movement is that a system of predominantly west or east winds is set up over the Earth, as shown in Fig. 5.11.

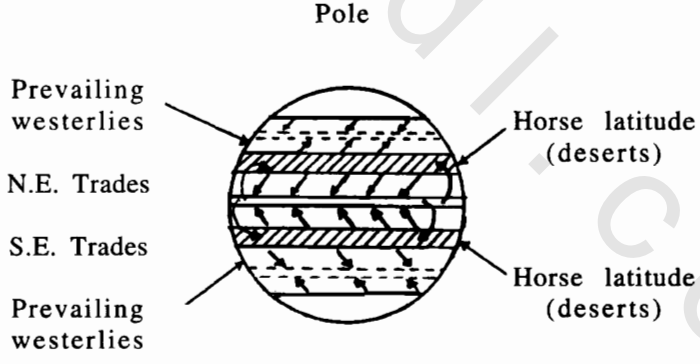


Fig. 5.11

Near the equator the heated air rises and then moves toward the poles high in the troposphere, with the surface return flow forming an east wind called **Trade Winds**. Due to this air circulation, deserts

tend to form on land in the regions of descending air. In these regions little horizontal movements of air take place, and they are called horse latitudes. The region of prevailing westerlies is not characterized by steady air flow, like that of the trade winds, but by waves, surges, disturbances, etc., which form the weather in these areas.

B.1.3. Climate changes

Presently, it is well known that the temperature of the surface of the Earth is increasing at a rate of about 0.5 °C in the last 100 years. Scientific records show that this increase is five times greater than what ought to be. Within the last 1000 years the average increase did not exceed 1 °C. This rapid increase today is due to the greenhouse effect and the increase of concentration of gases, like CO_2, in the upper atmosphere, thus causing this heating effect due the absorption of infrared rays coming from the Sun.

Three factors cause the increased concentration of the greenhouse gases in the atmosphere:

1. Increased population density on Earth.
2. Pollution made by man or industry.
3. Excessive production of modern technologies and their after effects.

The above factors have direct impact on the biosphere on which the life cycle on Earth depends. Aubery Meyer put a model of the biosphere as a "closed system" with internal flow, or feedback throughout the system and a transtemporal progression based on this loop, see Fig. 5.12. This model makes the biosphere loop to be looped upon itself with three crossover points. These give rise to the appearance of three subloops or petals, all sharing a common space to the "knot". The common space at the center represents the shared geosphere/biosphere upon which all human activities depend. The petals are assigned to represent humans and their activities, i.e. the three P's: Pollution, population and production, and the growth of each of them.

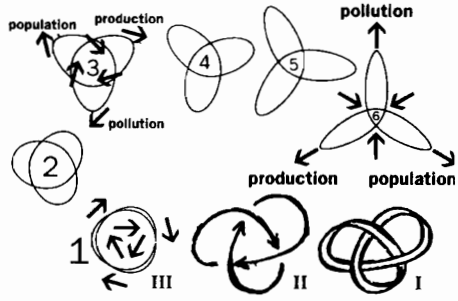


Fig. 5.12. The human impact on the diminishing ecological space.

The growth and progression of human activities takes place and so the loop goes through stages of transformation. The growth of these parameters increases feedback between them. The model shows how these are now impacting on each other and at the same time closing on the biosphere. It is this growing prevalence and proximity of human impacts, that diminishes the ecological space which is now changing the global climate.

B.2. Radiation balance on Earth

Why is Earth so conformable for human beings and is suitable for life in general? The basic answer to this question lies in the radiation balance that maintains suitable temperature for life on Earth. The Sun is a black body at a temperature of about 5800 K. According to Stefan's radiation law, the power radiated per unit area from the Sun is

$$\text{Solar flux} = \text{Total power radiated / Surface area (A)}$$

$$= \sigma T^4$$

where σ is Stefan's constant, 5.67×10^{-8} $W/m^2.K^4$. From this we can calculate the sun's radiated energy flux to be 6.4×10^7 W/m^2 at the surface of the photosphere. Using the inverse square law for the decrease in intensity with distance, we get:

Flux at Earth's orbit= Solar flux x $(R_{Sun} / R_{Earth\ orbit})^2$

$$= 6.4 \times 10^7 \ W/m^2 \times (696 \ M\ m / 1.5 \times 10^5 \ Mm)^2$$

$$= 1380 \ W/m^2 \ .$$

This is just about the value found experimentally for the solar constant.

Using Wien's displacement law, $\lambda_{max} . T$ = constant = 2.9×10^{-3} mK, the maximum wavelength of the Sun is 500 nm in the visible region.

Earth is not a black body, it is a grey body, it absorbs only about 70% of the incident solar energy. A body that takes energy from its surroundings increase its temperature. This causes Earth's temperature to be above absolute zero. In turn, its non-zero temperature, implies that the Earth radiates energy. Again, if we use Stefan's law and the Earth's temperature we can find the emitted flux.

Radiation balance basically determines the Earth's temperature. As viewed from the Sun, Earth appears to be a circle of radius R, the radius of the Earth (6400 km). The solar power flux at the Earth's orbit is about 1.4 kW/m^2, so that taking into account that Earth absorbs only 70% of the incident radiation, the total power incident on the Earth is $[(0.7)(1.4\ kW/m^2)(\pi R^2)]$.

From Stefan's law, the surface of Earth radiates a total power of $[(4\pi R^2)\ \sigma T^4]$. Setting the incident and radiated power equal, we find:

$$[(0.7)\ (1.4\ kW/m^2)\ (\pi R^2)] = [(4\pi R^2)\ \sigma T^4]$$

Solving for T, we get: $T = 255$ K

Wien's displacement law gives, $\lambda_{max} = 11.4\ \mu m$ for T = 255 K. This wavelength is in the infrared, indicating that Earth radiates in the infrared.

B.2.1. The global temperature distribution

The solar radiation that falls onto the ground is not the same at different points on the Earth because Earth is not a flat disk as was assumed in radiation balance discussion. It is a sphere. A surface area (dA) at latitude, θ, has an effective area = $dA \cos \theta$, with respect to the incident solar radiation. Thus the intensity of solar radiation falls off as $\cos \theta$ as one moves toward the polar regions (see Fig. 5.13). The difference in radiation intensity received results in differences in temperature among Earth's regions. Heat transfer goes from the hotter to the colder regions.

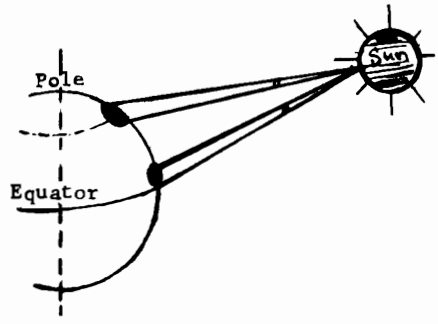


Fig. 5.13. Equal solid angles cover more area near the poles than the equator.

Radiation travels in straight lines, so radiant energy cannot be responsible for the reduction of temperature differences on the globe.

Conduction is also a minor source of equalization. It is convection, involving both gaseous air and liquid water, that must play a major role in minimization of temperature differences.

Wind helps to make these differences smaller. Cool air moves from the poles toward the equator, warm air flows from equatorial regions.

Three-quarters of the globe is water surface, so oceans are important in absorbing solar energy at one place and releasing it somewhere else causing ocean currents. Besides, solar energy supplies the latent heat of vaporization in low latitudes. The water vapor becomes part of the atmosphere. and moves with the air to higher latitudes. Eventually, rain falls where the temperature is lower, releasing the latent heat absorbed in the equatorial regions.

Under normal conditions used to prevail on Earth previously, the winds, the water vapor in air, the temperature and the water cycle determine the weather in a certain locality. At present, the study of these parameters and their deviations from the means, is of major importance because of the spreading of pollutants by these factors. The increase of concentration of the greenhouse gases in air and the subsequent effect on the Earth's temperature has to be critically considered when the problem of climate changes is discussed.

B.2.2. Physics of the atmosphere

Familiar physics principles and the kinetic theory of gases can describe the motion of the atmosphere. We are going to describe bulk motion of a fluid by its steady stream line flow. While it is true that real flows are not usually irritational, one can describe a good deal of behavior of the atmosphere in terms of the velocity field as a function of position. The flow must conserve mass, i.e. it must obey the equation of continuity. This could be simply written: ρ = constant, for which the equation of continuity is: $v\ A$ = constant. We consider infinitesimal air packets obeying the ideal gas law:

$$P = \rho R T \qquad \text{at least when air is dry.}$$

For the ideal gas the equation for an adiabatic process is

$$P V^{\gamma} = \text{constant}$$

or

$$T P^{-R/C_P} = \text{constant}$$

This last equation could be found directly from:

$$T V^{\gamma - 1} = \text{constant}$$

characterizing the adiabatic change, and

$$C_P - C_V = R \ ; \ C_P / C_V = \gamma$$

Thus, the temperature of a dry air packet changes with altitude. This is called **the adiabatic lapse rate**, and the cooling effect of the adiabatic expansion is about 10 °C per km.

Energy must be conserved for the infinitesimal packets of air, so that the net heating rate is:

$$dQ/dt = T\, dS/dt = C_p\ dT/dt - (1/\rho)\ dP/dt$$

$$dQ = C\, dT - P\, dV = C\, dT - (1/\rho)\ P$$

The heating of the air packet includes the effects of incident solar and terrestrial radiation, latent heats, friction, turbulence, and boundary layer heating near the ground. The humidity affects the energy balance through sources and sinks of water vapor.

In principle, we can solve the equations of the atmosphere's motion. However, it is not at all easy. In practice, instead of infinitesimal air masses, one must take averages over cells containing large numbers of molecules. This average calculations produce coarseness in the results due to the coarseness of the data themselves.

Since the equations of motion of the atmosphere are nonlinear, one could not solve the weather completely in a deterministic fashion. Recent ideas about chaos, show that nonlinear equations lead to solutions that depend strongly on initial conditions, none of which are known very well. In addition, slight differences in initial conditions grow exponentially in their effects. Thus, the round off errors lead to uncertain results. The solution of these nonlinear equations exhibit what we called chaos. The atmospheric behavior in the area called **Bermuda Triangle** is an example of the chaotic behavior of the motion of the atmosphere.

B.2.3. The CO_2 molecule and the greenhouse effect

The CO_2 molecule has a structure shown in Fig. 5.14. The shared electrons provide the bond holding the molecule together. Clearly, there is some fixed equilibrium distance of the oxygens from the

carbon. If the system is perturbed, the atoms may move relative to one another. To get an idea of the energy stored in the molecule, we imagine the bonds between the atoms as springs of force constant k, with equilibrium separation of the oxygen and carbon atoms. Different vibrational modes of CO_2 molecule are shown in Fig. 5.14. Different eigenfrequencies could be found. Strong resonances in the atmosphere were found to occur near: 3.60, 3.85, 4.00, 7.80, 8.10, 9.30, 10.40 and 10.80 μm in wavelength. The eigenfrequencies of the vibrational modes for carbon dioxide are in the infrared. Other greenhouse gases existing in the atmosphere have resonances in the infrared. Earth itself radiated in the infrared, as predicted by our application of Wien's displacement law.

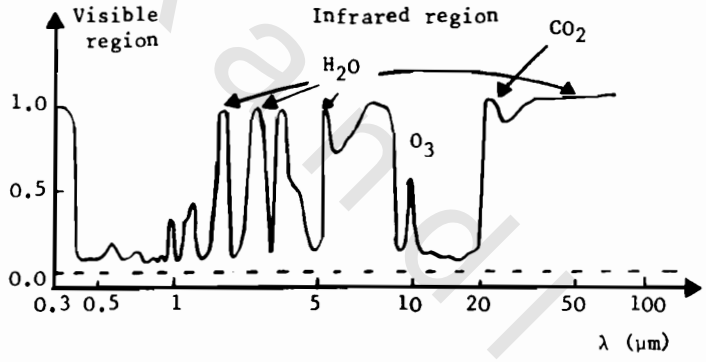


Fig. 5.14. Clear weather atmosphere absorption near sea level.

Thus, if infrared radiation from Earth with a frequency near the eigenfrequency impinges on a greenhouse gas molecule, it will be absorbed, exciting the molecule's modes. The radiation is then reemitted, but the photon may travel in any direction. Thus, half of the infrared radiation emitted by any molecule is directed back to Earth. The net result of absorption and reemission is a warming of Earth. This is known as the greenhouse effect. The effect of infrared absorbers is apparent in the plot of atmospheric absorbance, Fig. 5.14.

Figure 5.14 shows the atmospheric window, i.e. the gap in absorbance in the visible region, as well as the absorbance of various

greenhouse gases. Water vapor is a large component in the lower atmosphere, besides, it has many resonances in the infrared and so plays an important role in the atmosphere's infrared absorption. As a result of presence of greenhouse gases the mean Earth temperature is 287 K, not 255 K. The upper atmosphere is at a temperature 255 K as determined by the radiation balance.

B.3. Global warming

The Earth's temperature as measured from space, by studying its electromagnetic radiation output is about -19 °C. Fortunately for us, the Earth's average surface temperature is +14 °C, far warmer than that detected from space. The extra 33 °C is due to the earth's surrounding "blanket" of atmospheric gases. This warming is called **the greenhouse effect.** It is not nitrogen and oxygen that form the bulk of the Earth's atmosphere, that are responsible of this greenhouse effect. The effect is due to certain trace gases, mainly water vapor and carbon dioxide. The beginning of this problem was through fuel combustion which is the source of most of the energy for our industrial society. Combustion of fossil fuel produces carbon dioxide, a greenhouse gas. Global warming became a problem since the beginning of the industrial age.

The photosynthesis reaction made by plants and green trees provide the natural balance between oxygen and carbon dioxide in the atmosphere. At present, the increase in the concentration of CO_2 in air due to fuel combustion, together with deforestation that is taking place here and there on Earth, aggravates the problem of global heating. It is now due time to begin steps to minimize production of greenhouse gases, in order to avoid climate destabilization. The following advices are made:

a. Control and reduce the burning of fossil fuel and biomass.
b. Improve energy efficiency in industrial processes.
c. Control deforestation and rationalize timber trade.
d. Use renewable energies.
e. Stabilization should be made for human population and the livestock population on a global level.

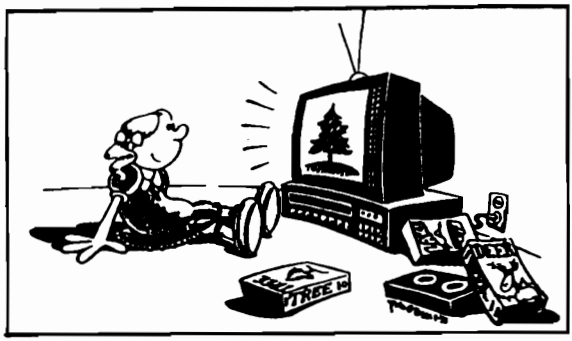


Fig. 5.15. "Back to nature".

B.3.1. Effects of global warming

i. Agricultural changes:

The species of plants grown in each region of the world would have to change. Climate change is associated with vegetation shift. Farmers use plant crops to make their living. They would likely change both their crops and their farming methods. Many of them might just move northward. A study in the United States predicted that a shift in the corn belt of 175 km either southwards or northwards would take place for each 1 °C change in the growing season mean daily temperature. Also, the yield decreases by several percents.

The change in the water cycle on Earth might change water supply in the different regions of the world. Desertification might be seen over normally planted areas. The expected reduction in the water flow in rivers is catastrophic for irrigated agriculture in dry regions. This might cause wars to erupt to attain water and control their sources.

ii. Sea level rise:

The sea levels have risen 14 cm over the last century, with a rise of 23 cm in the second half of the century. In 1989, it was published that there is a globally coherent rise of about 0.25 cm per year at the

present time. Part of the rise is due to thermal expansion of water as a result of the 0.5 ^{o}C rise in temperature since 1880. The building of Dams to store water in reservoirs might help to stop this rise in sea level.

Since the temperatures will rise more near the poles, the north ice cap, which is only meters thick and rests on seawater, will melt. This melting might affect climate trend by decreasing Earth's albedo, since ice reflects sunlight better than open water or ground.

B.3.2. Minimizing the impact of the greenhouse effect

Human beings are rapidly adding greenhouse gases to the world, mainly due to the burning of fossil fuels. It could be easily shown from the amount of coal and oil burnt each year that we put one ton of CO_2 per human each year (!). We have seen that CO_2 and other greenhouse gases are formed of molecules that might resonate with the infrared radiation incident on it. This is due to contributions from rotational and vibrational motions of the molecule. The greenhouse gases: CO_2 , CH_4 , NO_2 and steam have polyatomic molecules. The existing of large number of degrees of freedom in each of these molecules allows heat and infrared radiations coming from the Sun to be absorbed. It is this inherent property of their structure that makes them "greenhouse gases" since their natural concentration in the atmosphere means that not all the solar radiation reaching the planet is returned to the outer space, but is held back. This blocking of part of the infrared radiation and its reflection back towards the surface of the Earth is known as **the greenhouse effect.** This effect makes the temperature on earth suitable for life.

With the burning of fossil fuels and the industrial revolution the atmospheric CO_2 concentration have risen greatly during the last decades. Biomass combustion is responsible for most NO_2 emissions into the atmosphere, apart from volcanic eruptions which we humans do not control. Fertilizers also produce considerable quantities of NO_2 . Another important source of NO_2 emissions are combustion processes occurring at very high temperatures. One example is the internal combustion engine used in automobile transport.

Methane gas (CH_4) is produced through the animals digestive processes. Rice cultivation also leads to important emissions of methane.

The increased concentration of greenhouse gases caused a thermal pollution to the atmosphere. This pollution increased the temperature of the Earth's surface by about 0.5 degrees above normal in the last 100 years.

B.3.3. How to avoid climate destabilization?

The continuous increase in the temperature of the earth's surface should be controlled otherwise global disaster will surely happen.

Fig. 5.16. We are all sitting in one boat. Either we all live or we all sink together.

The following advices are made to avoid future climate destabilization:

a. Control and reduce the burning of fossil fuel and biomass.
b. Avoid the use of electricity from thermal power stations.
c. Improve energy efficiency in industrial processes.

d. Use renewable energies.
e. Reduce, reuse and recycle residues.
f. Reduce industrial transport of goods and the use of automobiles.
g. Control deforestation, and rationalize the timber trade.
h. Avoid burning organic material to no purpose.
i. Stabilization should be made for human population and reduce the live stock population on a global level.

B.4. Atmospheric electricity

The atmosphere is a great electric machine. It is full of electric fields and electric currents. Thunderstorms are giant electrostatic generators sending negative charges to the ground and positive charges to the ionosphere which is good conductor and so the positive charge (ions) spread laterally over the entire globe. The equivalent electric circuit representing the atmosphere is shown in Fig. 5.17. The potential difference between the ionosphere and the ground is about 300,000 volts. The resistance between ionosphere and ground at fair weather is about 200 ohms. On the average the total electric power delivered by Thunderstorms to the ground is about a million of kW.

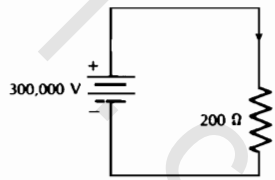


Fig. 5.17. Schematic diagram of the atmospheric electric circuit.

The ions in the ionosphere are continually formed by the impacts of cosmic rays on air molecules, by the ultraviolet irradiation of the upper atmosphere, and by natural and man-made radioactivity near the ground. The atmospheric electric field points vertically downward. The average value of the strength of this field is 130 V/m, depending on local conditions. The lines of force end on the surface of earth, thus, there must be negative charge on the surface. The amount of charge per unit area is given by gauss law as:

$$\sigma = \varepsilon_o E = - 8.85 \times 10^{-12} \times 100 \text{ C/m}$$

$$\sigma = - 10^{-9} \text{ C/m}^2$$

The total negative charge on the surface of the Earth including oceans is about half a million Coulombs.

B.4.1. Thunderstorms

Thunderstorms obtain their mechanical and electrical energy from humid air. Thunderstorms are heat engines; their heat reservoir is the heat of evaporation stored in water vapor. One cubic kilometer of air at 17 °C and atmospheric pressure and 100% relative humidity contains 1.6×10^7 kg of water vapor. Since the latent heat of vaporization for water is 586 kcal/kg, at 17 °C then if all the water vapor in this cubic kilometer of air condenses, an amount of energy of about 9.2×10^9 kcal is released. This energy is equivalent to the energy released by exploding of about 9000 tons of TNT. The transfer of only a small fraction of this huge energy would be capable of producing Thunderstorms, Tornadoes and Hurricanes.

A Thunderstorm is made of several cells, i.e. Thunder clouds, in which air moves upwards at first and in later stages it moves downwards. The rising motion of air is powered by the heat released in the condensation of water vapor.

B.4.2. Lightning

An electric discharge in dry air under atmospheric conditions requires an electric field of 3×10^6 V/m. The presence of water drops and the reduced atmospheric pressure in a Thunder cloud favor breakdown and therefore, sparking is likely to begin at lower electric fields. A lightning discharge can take place between the opposite charges inside the Thunder cloud, or between the Thunder cloud and clear air, or between the Thunder cloud and the ground.

A typical flash of lightning between a Thunder cloud and the ground begins with an electron avalanche in the intense electric field near the negative charge of the Thunder cloud. As the avalanche moves downward it leaves behind a channel of ionized air or plasma;

electrons from the cloud flow into this channel, giving it a negative charge. The concentration of negative charge near the tip of the channel generates strong electric fields which continue to push the avalanche along, see Fig. 5.18. The channel has a radius of several meters but only its central region is luminous. It follows a random path depending on the variations in the density of free electrons in the air ahead of the avalanche. In Fig. 5.19, a sequence of diagrams, based on high speed photographs, shows the downward motion of the avalanche and the return stroke. When the tip of the lightning comes near to the ground an intense electric field is initiated and an upward moving charge will meet the channel at a height about 20-100 m above the ground. At this moment the circuit between cloud and ground is complete. Negative charge can flow from cloud to ground with little resistance.

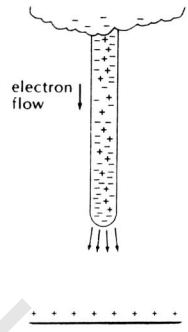


Fig. 5.18. The electron avalanche from the cloud making a channel of ionized air. Approaching the ground, the intense electric field created initiates a discharge from the ground forming the return stroke.

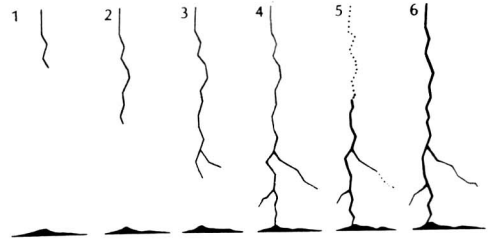


Fig. 5.19. A sequence of diagrams showing the downward and the upward motion of electron discharge in a lightning.

The energy dissipated in the lightning channel is about 10^9 J. Most of this energy goes into heat.

B.4.3. Transport phenomena in gases

i. Molecular motion and pollution in the Earth's atmosphere:

The Earth's atmosphere is defined as the layer of gas that surrounds the planet Earth. There is no definite limit to the atmosphere. The density of air decreases greatly with height and the molecular mean free path might become greater than several kilometers. The properties of the atmosphere change with altitude. Ten kilometers above the surface of Earth is the troposphere where the rate of decrease of temperature with altitude is about 6.5 ^oC per kilometer.

The stratosphere comes after the troposphere up to about 30 km. From 30 km to about 80 km we have the mesosphere where ionization and molecular dissociation processes and various chemical reactions induced by the Sun's radiations become significant. The ozone layer is situated in the mesosphere and is responsible for the scattering of most of the ultraviolet radiations from the Sun, thus protecting us from its harmful effects. The ozone layer problem originates from here. The chloro-fluoro-carbon used in the atomizers and the freon gas used in refrigerators react chemically with the ozone gas in this layer thus depleting parts of it from ozone and causing a hole from which intense ultraviolet rays reach the Earth's surface. The increase in cancer skin observed in several parts of Earth is attributed to hole in the ozone layer and the intense UV radiations to which people are exposed.

ii. Molecular motion and Maxwell's distribution function:

Robert Brown was the first to report that pollen grains suspended in a liquid move erratically from one place to another, as if under constant agitation. Afterwards, Einstein attributed this erratic motion, known as the Brownian motion, to the bombardment of the invisible molecules of the liquid to pollen grains.

When we say that a gas is in the steady state, we do not imply that the velocity of any one molecule remains constant. But if we examine the whole of the molecules at any instant, the number of molecules n_u having velocities between certain prescribed limits, u and u + du , does not change by collisions, i.e. this number remains the same independent of time. The law which expresses n_u in terms of velocity u is called the law of distribution of velocities and was first derived by Maxwell.

In the present treatment for the derivation of Maxwell's law we will be aided by the formula for the variation of pressure of air with height, h, namely:

$$P = P_o \exp[- h/H] \quad , \quad H = k T / m g$$

m is the molecular mass and T is the absolute temperature, P_o is the air pressure at the Earth's surface.

Consider a cylinder of cross-section 1 cm^2 enclosing a vertical column of air under the action of the Earth's field of gravity. The temperature is supposed to be uniform and constant throughout.

Consider now the mobility of gas molecules in the column. The layer of gas contained within x and x + dx is traversed by molecules coming from the bottom and going upwards and also by another stream of molecules moving in the opposite direction, see Fig. 5.20.

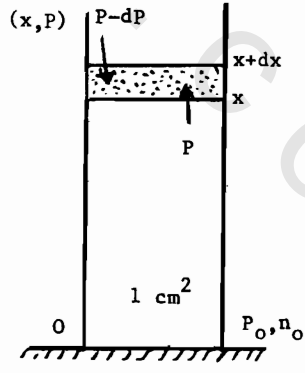


Fig. 5.20

A molecule starting with velocity u_o upwards from the layer x = 0 will be returned from the height $x = u_o^2 / 2g$. This happens when all kinetic energy ($1/2\ m\ u_o^2$) of the molecule is transferred to potential energy (mgx) . This shows that the molecular velocity u_o can vary from 0 to ∞ otherwise we have to set a limit to the height which can be reached by the gas.

Let the number of molecules that have velocities lying between u_o and $u_o + du_o$ at the level x = 0 be given by: $n_o\ f(u_o)\ du_o$.

The number of molecules that cross the layer dx upwards is given by:

$$n_1 = \int_{u_o=\sqrt{2g\ x}}^{u_o=\infty} \eta_b\ u_b\ f(u_b)\ du_b$$

The lower limit $\sqrt{2g\ x}$ is for all molecules having velocities less than this value which will be turned back before reaching the height x.

The number of molecules crossing the layer dx downwards is

$$n_2 = \int_0^{\infty} n\ u\ f(u)\ du$$

For equilibrium conditions n_1 should equal to n_2 . Knowing that the pressure of air at any height is proportional to the molecular density, then from the law of pressure we have:

$$n = \eta_b\ \exp\ [-\ m\ g\ x\ /\ k\ T]$$

Also, from Newton's law of motion:

$$u_o^2 = u^2 + 2\ g\ x$$

Therefore $$u_o\ du_o = u\ du$$

By substitution we get by eliminating u_o :

$$\int_0^{\infty} f(u^2 + 2 g x)^{1/2} u \, du = \exp[- m g x / k T] \int_0^{\infty} f(u) u \, du$$

By removing the integrals we get the equation:

$$f(u^2 + 2 g x)^{1/2} = \exp[- m g x / k T] \; f(u)$$

This is a functional equation and is only satisfied if the function f is of the form:

$$f(u) = A \exp[- m u^2 / 2 k T] = A \exp[- E / k T]$$

where E represents the average kinetic energy of a molecule. This is Maxwell's law, and f(u) is known as Maxwell speed distribution function.

The speed distribution of gas molecules at a certain temperature is shown in Fig. 5.21. The curve is known as Maxwell's distribution curve.

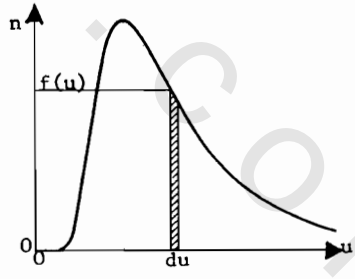


Fig. 5.21. Speed distribution of gas molecules at a particular temperature.