SCIENCE, SOCIETY, MICRO COSMOS

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ABSTRACT

Knowledge of the microcosmos is essential so that we can understand and solve basic issues of contemporary society. Knowledge of nuclear reactions helps in assessing the dangers of nuclear war and appreciating energy potentials of fission and fusion. Knowledge of effects of radiation on tissue permits the estimation of risks of cancer and genetic changes. Knowledge of interactions between electromagnetic radiation and the atmosphere gives an insight into the greenhouse effect. Examples of the uses of particles from accelerators include radiation surgery, cancer therapy, the purification of exhaust gases, the measurement of the structure of viruses and the determination of the elemental composition of cells.

1. THE ALPHABET OF MODERN SCIENCE

Quantities in the macroscopic world are measured in kilograms, seconds and metres whereas in the microscopic world, mass, time and length are not sharply defined quantities. Instead of measuring weight, one counts particles; instead of measuring time, one counts cycles of an electromagnetic wave tuned to the energy difference between two atomic levels; and instead of measuring length, one analyzes scattering patterns.

The foundation on which modern science is based, may be summarized in five statements assigned by the letters A-E.

A defines the smallest piece of a given substance as a molecule; of a given element as an atom; and of a given nuclear mass as a nuclide. Having defined the type of molecule in a substance, the number of molecules is directly related to the weight of the substance. A molecule may be simple, like $H_2$ or $CO_2$, or more complex like glucose $C_6H_{12}O_6$ or a protein in the mass range of 10-100 000 atomic mass units. Recently molecules up to 23,000 atomic mass units have been determined with atomic precision using time-of-flight techniques on molecules desorbed from a thin sample.

The particle interpretation of matter becomes more and more evident in contemporary science and technology. The invention of the tunneling microscope, for which the Nobel prize was awarded in 1986, was a great step towards refined atomic structure
determination. Studies of surfaces and junctions, for example junctions between the amorphous and crystalline parts in semiconductors, profit a great deal from the improved microscopic resolution.

B identifies the particle character of energy transfer. It may manifest itself as photons in the energy emitted from the sun or the light absorbed on our retina. It may be the electrons released from a hot cathode or the electrons transferring the picture to a TV screen. It may also be ionizing particles being emitted from a radioactive nuclide to be absorbed in material, organic or inorganic. The fact that energy transfer is mediated by particles has many consequences for our interpretation of the world of radiation. Some of these consequences will be discussed below.

C is connected with reactions between particles, a study of which assists the exploration of the microcosmos. The results of particle interactions depend on the character of the mediating force. Different forces act at different collision energies. At very low energies, the interactions between neutral atoms are mediated by the oscillating electric dipole moments, a consequence of the displacements of negative and positive charges within the atom. These van der Waals forces bind for example helium into a liquid. In tissues of the human body, the energy level (37°C) favours second-order interactions. For example, the electrostatic forces between neighbouring charges of opposite sign help to stabilize long chains of proteins or DNA. These electrostatic forces, which act in the hydrogen bonds uniting hydrogen with nitrogen or oxygen or fluorine, are important for the dynamics of the living cell. The dynamics of chemical reactions, involving colliding molecular beams are of such significance that in 1986, the Nobel prize was awarded for the furthering of our knowledge in this field.

The energy conditions prevailing in the interior of the sun are very different and nuclear reactions take place. There, the temperature is so high that electrons and ions are no longer bound into atoms. In this dense hot plasma, reactions take place under the influence of three forces; the weak force, the electromagnetic force and the strong nuclear force: the reaction products have kinetic energies in the MeV range.

D defines quantum mechanics as a basic ingredient for explaining the behaviour of reactions and of composite bound systems. The birth of quantum mechanics dates back to the days when radiation of heat was explained as being due to the quantification of energy.

Matter and radiation behave sometimes as waves and at other times as particles. The wave picture of matter explains the working principle of the tunneling microscope. The particle picture of radiation explains emission and absorption processes. The space dimensions of composite systems, like molecules or nuclei are explained by the fact that standing waves, describing particle positions with respect to one another, require space. Rearrangements of the wave structure are limited by the boundary conditions of the system. Hence only discrete values of wavelength and hence of energy are permissible.
E identifies the scale of the microcosmos. As we know from quantum mechanics, the relative kinetic energy between bodies, free or bound, is related to the scale of their interaction: the higher the energy, the smaller the space-time dimensions. Thus the scale is dependent on the energy of the radiation initiating the reaction. In biology and chemistry, slow neutrons and X-rays are used to study the structure of molecules by diffraction techniques. In atomic and solid state physics, photons and electrons in the eV and keV ranges are most commonly used radiations. In nuclear physics, a variety of particles in the MeV range are being used to study the atomic nucleus in terms of its nucleon constituents. The Low Energy Antiproton Ring (LEAR) at CERN is one of the most interesting recent additions to accelerators in the intermediate-energy range.

The energy scale of nuclear physics may have to shift more into the GeV range as there are indications that a detailed explanation of nuclear physics phenomena has to be based on the quark concept. Present studies at the CERN Super Proton Synchrotron (SPS) make use of oxygen ions and muons to bombard nuclei in order to try to reveal a structure of more than three constituent quarks. High energy physics dealing with the smallest particles and the shortest distances demands still higher energies. Therefore, exploration of new acceleration and detection principles and the development of new technologies are closely linked to progress in high energy physics.

Advances in experimentation often provide important spin-off effects in other fields. One example of spin-off effects is the radiation from synchrotrons, which is utilized increasingly in science and technology. Another example is the variety of radiation sources and detectors used in medicine. At this meeting, technologies such as superconductivity and ion implantation have also been discussed.

Below, I should like to demonstrate how some of the basic concepts used in the exploration of the microcosmos are so important for the best interpretation of our contemporary world and of the changes which take place in it. In my opinion, it is by keeping viable and advancing the knowledge of the microcosmos which makes our scientific work most valuable to society. Some examples will illustrate how knowledge related to the accelerator and radiation sciences is employed in the fields of energy, environment and health.

2. ENERGY

Detonation of a single atomic bomb on August 6, 1945 devastated the city of Hiroshima. The instant release of energy equivalent to 13,000 tons of TNT was sufficient to convert everything within a radius of 2000 meters to practically a desert.

The bomb caused burns on people within 4000 meters and those within 1000 meters had their skin, red bone marrow and intestines badly damaged. Over 200,000 people died. It was said at the time that no vegetation could grow for 75 years.
The energy released by the bomb on Hiroshima was derived from fission of 1 kg of uranium. A mass of 1 gram converted to energy, and according to the formula $E=mc^2$, this would be sufficient to provide Sweden with energy for 20 minutes. The biggest bomb tested so far released an explosive energy corresponding to 68 million tons of TNT, equivalent to 5,000 Hiroshima bombs.

Today, five countries are known to possess some 50,000 nuclear bombs with a total explosive power of 15,000 million tons of TNT. This corresponds to one million Hiroshima bombs and the inherent energy would be enough to provide Sweden with energy for 40 years. It is hard to grasp the meaning of these figures but if one is in Hiroshima their significance becomes awsome. Olof Palme, in his speech in the Peace Memorial Hall of Hiroshima, recommended that political leaders from all nations should go there to convince themselves that the Hiroshima disaster must not happen again.

One of the challenges facing mankind is avoidance of a global war. Another is to ensure the future supply of energy. From the known reserves and the present rate of consumption, oil will last 35 more years, uranium 50, gas 60 and coal 300. More supplies of these non-renewable energy sources will certainly be found but the energy consumption is also predicted to increase. The Fig. 1 from Ref. (1) shows a projection 100 years ahead on the global use of energy. The energy consumption was computed for three different scenarios A, B and C. Different assumptions were made about the evolution of different parameters such as the gross national products and the world population. In the high-energy scenario, A, a technical and economical break through for extracting shale oil is assumed to occur by the year 2010. In 2075 the population is assumed to be 11.4, 8.4 and 6.3 billion people for the three cases A, B and C. It is expected that more reserves of gas and oil than are known at present will be found as oil and gas are assumed to be available by 2075. A large increase in the use of coal (solids) is predicted for all three cases. C is the low-energy scenario for which a rapid development of non-fossil energy sources is assumed.

![Global primary energy by fuel 1975-2075 (in exajoules). The three scenarios A, B and C are described in the text. From DOE report /ER-0239.](image)

Fig. 1 Global primary energy by fuel 1975-2075 (in exajoules). The three scenarios A, B and C are described in the text. From DOE report /ER-0239.
Assuming that breeder reactors will not operate on a large scale, the energy from nuclear-fission reactors will be of limited significance. At present only 3 per cent of the global energy comes from fissile nuclear fuel whereas 80 per cent comes from fossil fuels. In 1986 there are 364 commercial nuclear reactors in operation and 181 under construction.

A process of great potential for the future energy of the world is nuclear fusion. Therefore, great efforts on fusion research are being made particularly in USA, USSR, Japan and Europe. In a fusion reaction between two light nuclei, one or more nuclei with stronger binding than the initial nuclei are produced. For example, the fusion reaction between two deuterium nuclei leads either to a (He, n) final state and a kinetic energy of 3.2 MeV, or to a (H, p) state and 4 MeV. The fusion of tritium with deuterium leads to a (He, n) final state and a kinetic energy of 17.6 MeV. In order to have ignition of a deuterium-tritium plasma, the temperature must be 50 million degrees and the product of density and confinement time must exceed 10^{20} s/m^{3}.

The deuterium isotope is present in sea water at a concentration of one part in 6 000. Thus each litre of sea water contains exploitable energy corresponding to that in 300 litres of oil. Different disciplines are of importance for fusion research, plasma physics being one of the most important. There are many similarities between the field of fusion and that of accelerator physics and technology. The particle motions in electric and magnetic fields have to be well known and high-power devices are needed to generate the fields.

There are two basic schemes, magnetic and inertial confinement, to enclose sufficient amounts of matter adequately long to yield energy. In the inertial confinement schemes a small pellet of frozen deuterium-tritium mixture of very high density is heated by intense radiation for a very short time. The heating may come from high-power lasers or from particle accelerators. To reach break-even (energy consumption = energy production) it is necessary that 300,000 joule be deposited in less than a nanosecond. This is about a factor of 10 above what is possible with the present technology.

Magnetic confinement aims at finding a geometry of the magnetic field such that the hot particles in the plasma are prevented from hitting material of the enclosure. The density is much smaller than that of inertial confinement and the confinement time is much longer. The best results on plasma confinement have been obtained in Tokamaks based on toruses in which there are both polar and azimuthal magnetic field components. The plasma may be heated by a radio-frequency system tuned to a cyclotron frequency of the ions rotating in the plasma. Another method of heating is by injecting a neutral high-intensity hydrogen beam which deposits its energy when slowed down in the plasma. There are 73 major Tokamak projects distributed over the world. The biggest European project is JET, Joint European Torus, situated at Culham, England. There are hopes that this machine provides an ignited plasma.
3. ENVIRONMENT

Soil, water and air interchange carbon, nitrogen and oxygen. These interchanges however are not in balance due to human activity. They are modified by chemical fertilizers, deforestation, and extensive use of fossil fuels. As a result, the CO₂ content of the atmosphere increases steadily and there is a drain of fertilizers, especially nitrogen, from soil to water. A variety of sophisticated materials, liquids and gases are also produced which do not fit into natural recirculation schemes or cycles. Thus, the environment issue assumes enormous proportions. The discussion will be focused on the production of CO₂ and acid substances related to the burning of fossil-fuel and the production of radioactive substances arising from nuclear energy.

The temperature of earth is regulated by the balance between the influx of solar energy and the radiation of heat into space. The heat-radiation spectrum has on an average, a maximum at a wavelength of 20µm corresponding to a ground temperature of +15°C. Part of the radiated energy is absorbed by the molecules of water vapour, H₂O, and CO₂ which absorb readily radiation of this wave length. Concerning CO₂ there is a marked absorption around wavelengths of 15µm corresponding to strong molecular energy transitions. Basically, it is 0.2 per cent of H₂O and 0.0345 per cent of CO₂ in the atmosphere which regulates the earth's temperature at +15°C instead of -20°C.

Because of the deforestation and the use of fossil fuel, the concentration of CO₂ has increased from a fraction 0.028 of the atmosphere content during preindustrial times to 0.0345 today. In 1958 the measured value was 0.0315 which gives an idea of the present rate of increase. Today 5.10¹² kg of carbon, 1,000 kg for each person on earth, in the form of CO₂ is produced annually from fossil fuel burning. Half of this remains in the atmosphere; the other half is reabsorbed in vegetation and the oceans.

The change in average global temperature is estimated by the use of sophisticated computer codes based on models which are necessarily very approximate. Calculated increases are in the range 1.5 to 5.5°C for a doubling of the CO₂ (2). The increase in temperature is predicted to be higher above land areas than above the sea where the interaction of the atmosphere with the water moderates the temperature changes.

Large scale gasification of other substances such as freon, methare and nitrous oxide also contribute to the greenhouse effect. In a recent NASA report (3), these gases have been estimated to contribute as much to the temperature increase as CO₂. Freon, which is known as a quenching gas in gaseous detectors, used on a large scale in spray cans, refrigerators and heat pumps is particularly dangerous. In addition to their contribution to the greenhouse effect, the freon molecules, consisting of carbon, fluorine and chlorine, most probably destroy the high-altitude ozone layer which protects us from solar UV radiation. There are thus many reasons for reducing drastically the use of freon which will remain for prolonged times in the atmosphere because it does not combine readily with other chemicals.
In a shorter time perspective, the production of oxides of sulphur and nitrogen and of heavy elements such as lead have to be reduced drastically. The catastrophic consequences of substances polluting European forests are shown in the Table 1 compiled by Sandra Postel in a Worldwatch Paper (4).

Table 1

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Area (thousands of hectares)</th>
<th>Estimated Area Damaged</th>
<th>Portion of Total Area Damaged (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>3,754</td>
<td>910</td>
<td>24</td>
</tr>
<tr>
<td>Belgium</td>
<td>616</td>
<td>111</td>
<td>18</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>4,600</td>
<td>1,250</td>
<td>27</td>
</tr>
<tr>
<td>East Germany</td>
<td>2,900</td>
<td>350</td>
<td>12</td>
</tr>
<tr>
<td>France</td>
<td>15,075</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hungary</td>
<td>1,600</td>
<td>176</td>
<td>11</td>
</tr>
<tr>
<td>Italy</td>
<td>6,363</td>
<td>400</td>
<td>6</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>82</td>
<td>42</td>
<td>51</td>
</tr>
<tr>
<td>Netherlands</td>
<td>309</td>
<td>138</td>
<td>45</td>
</tr>
<tr>
<td>Norway</td>
<td>8,330</td>
<td>400</td>
<td>5</td>
</tr>
<tr>
<td>Poland</td>
<td>8,677</td>
<td>600</td>
<td>7</td>
</tr>
<tr>
<td>Sweden</td>
<td>26,500</td>
<td>1,000</td>
<td>4</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1,200</td>
<td>408</td>
<td>34</td>
</tr>
<tr>
<td>West Germany</td>
<td>7,371</td>
<td>3,824</td>
<td>52</td>
</tr>
<tr>
<td>Yugoslavia</td>
<td>9,500</td>
<td>1,000</td>
<td>11</td>
</tr>
<tr>
<td>Other</td>
<td>39,087</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>135,964</td>
<td>10,609</td>
<td>8</td>
</tr>
</tbody>
</table>

As can be seen German forests are most severely damaged but also in Sweden with large forest areas, the damage is sizeable. According to the UN Economic Commission for Europe, Western Germany in 1980 acquired average monthly sulphur deposits of 77,800 metric tons of which 36 per cent were estimated to come from other countries. France acquired 12,100 tons, 48 per cent imported, and Poland 133,000 ton, 58 per cent imported. The smaller countries in general acquired large deposits from abroad. Norway had 25,000 ton of monthly sulphur deposits of which 92 per cent were from abroad.

Large resources are invested on research and development of processes which prevent acidifying substances escaping from chimneys. A scheme by which the exhaust gases are irradiated is of interest to accelerator scientists. The exhaust gases are first mixed with ammonia and the mixture is irradiated with high-intensity beams of electrons with an energy of a few hundred keV. The irradiation increases the rate of the chemical reaction in which the gaseous oxides of nitrogen and sulphur are converted to solid ammonium sulphates and nitrates. More than 90 per cent of the acid-forming pollutants have been removed in this way. The large flux irradiated up till now was
10,000 Nm³/s corresponding to the flux from an 8 MW oil-burning n Japan. In Germany also this technology is being tried and in Indianapolis there are plans for a facility using two 600 keV electron accelerators with a capacity to purify a gas flux of 24,000 Nm³/s.

The reactor accident in Chernobyl has demonstrated the potential dangers associated with radioactive waste in nuclear reactors. Under normal conditions, however, the waste is handled and deposited without any significant escape to the environment. The waste liberated in a reactor accident travels over large land areas and is distributed as determined by the wind patterns. Due to heavy rainfall when the fall-out from Chernobyl passed above middle and northern Sweden, comparatively large amounts of the two cesium isotopes, 134 and 137, were deposited there. Cesium-134 has a half life of 2 years and gives rise to a short-term problem whereas cesium-137 with a half life of 30 years remains for many years. Based on the fall out from tests of nuclear weapons during the 60's, the amount of cesium-137 in food is expected to diminish by a large factor, however, over the coming five years due to its dilution in soil and water. The main problem with nuclear energy despite Chernobyl remains the handling of plutonium-239 with a half life of 24,000 years. Besides emitting heavily ionizing alpha particles, this long-lived nuclide is also poisonous and it is a basic ingredient in the manufacture of nuclear weapons.

The effect of the Chernobyl fall-out on the state of health in Sweden is quite negligible. The probability of having cancer which is about 30 per cent during a life span, in Sweden, may increase due to the Chernobyl radiation by something between 0.002 and 0.02 per cent. This corresponds to absorbed doses between 1 and 10 millisievert. In Sweden, the main problem due to the Chernobyl accident has probably been caused by the low limit of 300 becquerel of cesium-137 per kg of food recommended by the Swedish authorities for radiation protection. Much meat from moose and reindeer has contained more than this recommended value, often as much as several thousand becquerel per kg. It has therefore been destroyed despite the fact that during the 60's the same high concentrations were found after nuclear bomb tests. The increased exposure from eating slightly radioactive meat can be figured out by knowing that 1 millisievert corresponds to about 100,000 becquerel of cesium-137 and that a normal person consumes 50 kg of meat per year.

Effects on the environment some distance from Chernobyl will probably be hard to detect. Despite Chernobyl, energy production based on nuclear fission can still be considered as one of the cleanest energy sources as far as ecological consequences are concerned. The 1,000 fold larger radioactive deposits from a nuclear war would undoubtedly have ecological effects influencing not only animals but also plants to such an extent that large areas of land may be affected.
4. HEALTH

In medicine, radiation and nuclear techniques are widely used. New imaging methods based on Nuclear Magnetic Resonance, NMR, and Positron Emission Tomography, PET, give valuable additional information to that obtained by X-ray tomography. In PET, short-lived carbon-11 positron emitters are first produced from an accelerator and by chemical methods they are subsequently attached to suitable molecules. These labelled molecules are then injected into the body. Positrons are emitted continuously for a few hours when the molecules spread and interact within the organs. The positron annihilates with an electron, after having passed a few mm in tissue; the two resulting collinear product photons are recorded in detectors external to the body. Space lines are reconstructed from detector pairs hit by the photons, giving an image of molecular activity. Examples of what is imaged and studied include the metabolism of glucose and the passage of heroin through the body. Many different substances can be labelled and it is quite appropriate to say that PET is an effective method of mapping the biochemistry of the body.

Cancer therapy is carried out by radiation from accelerators and from radionuclides. Nearly half of all cancer cases are treated by radiation which is as frequent as conventional surgery and more frequent than chemotherapy. In hospitals, only comparatively small accelerators for electrons or protons are in use. The patients are to a large extent treated by X-rays. At many accelerator centres, part of the program is allocated to medical applications. In Harvard, at Fermilab and in three Russians laboratories, Gatchina, ITEP Moscow and Dubna, protons of medium energy are used for surgery and therapy. For medical purposes, heavy ions are used in Berkeley and pions at SIN, the Swiss meson facility in Villigen. The first medium energy accelerator fully dedicated to medicine, a proton synchrotron, is being built presently at the University hospital in Loma Linda, California.

Already in the 50's, pioneering work in Berkeley and Uppsala (5) showed the advantage of using protons for medical treatment. A medium-energy proton of 200 MeV has a 25 cm range in tissue and thus can reach all points in the human body. The differential ionization and hence the cell damage is largest just prior to the protons coming to rest. In this respect, protons are different from X-rays and neutrons which ionize less and less as they penetrate deeper and deeper. Beam surgery, on small regions of the brain, initiated long ago in Uppsala, and radiation of small tumours of the retina, carried out at Harvard, Villigen and Moscow are two examples of local surgery in which medium-energy protons are preferred to other radiation particles.

The elemental composition of individual blood cells has been measured recently by the PIXE (Particle Induced X-ray Emission) method (6). One of the aims of the study was to find traces of heavy elements, in particular, mercury suspected of coming from amalgams. The uptake in tissues including blood could come from the inhalation of mercury vapour and from swallowing amalgam particles. Persons with vague symptoms but considered clinically healthy were examined and traces of mercury were found. In
countries with low natural concentration of selenium, Se, in the food, e.g. Sweden, some individuals might be vulnerable to alterations in the metal body burden. The low intake of selenium, in Sweden about 30 μg Se/day, and the normal intake of mercury from food, estimated at about 10 μg Hg/day, limits the biologically available selenium because it is already tied up by mercury. Selenium forms very stable compounds with ions of mercury and other metals, thus inhibiting their interactions at the molecular level in the cells. If other metals e.g. lead and cadmium (smokers might be a risk) are taken into account, the effective selenium intake in Sweden might be close to the very low intake in the Keshan disease area (8). Persons with many amalgam fillings and exposed to other metal sources might thus need a greater selenium supply in order to handle the increased metal body burden. The recommend dietary allowances (RDA) of selenium is 50-200 μg/day.

Individual cells were investigated using a proton beam 3 μm in diameter from the Studsvik van der Graaff accelerator (9). Red cells, white cells and platelets were separated by centrifuging whole blood. Each cell was then placed on an ultra-thin Formvar film, 20-30 nm thick, and the beam directed on the cell. After an interaction between a proton and an electron of an inner atomic shell, the emitted X-ray was detected. In this way, all elements from magnesium upwards could be traced down to a threshold concentration of 0.5 μg/g. About 90 per cent of people with vague symptoms, for example abnormal fatigue, muscle pain and burning mouth were found to have excessive amounts of mercury in 20-40 per cent of the cells. This shows that measurements of individual cells are important when compared with conventional methods such as neutron activation and atomic absorption spectrophotometry which measure the total integrated concentration of heavy metals and trace elements.

I would like to conclude this chapter by mentioning some results from an exciting, scattering experiment with a virus as a target. Viruses are small bodies able to penetrate cells and use the cell content for their reproduction.
The experiment was performed using synchrotron radiation from the Cornell synchrotron (10). A crystallized human common cold virus, rhinovirus 14, was assembled into a crystallized structure and used as a target. The analysis of the very complex pattern of the scattering radiation required a supercomputer. The 3D atomic structure, the first ever measured of an animal virus, reveals narrow canyons in the spherical shell of the virus. The canyon is about 25 ångström deep and may be the site for cell receptor binding. An antibody molecule whose fragment would have a size of the order of 35 ångström would not be able to reach the canyon floor. Thus the structure in the deeper part of the canyon would not be prone to immune selection and could remain constant, permitting the virus to retain its ability to seek the same cell receptor.

Research is presently in progress to find inhibitor molecules (virus antibiotics) that are small enough to reach the canyon floor. These inhibitors have either to block the receptor site or prevent ions from entering a channel into the virus thereby preventing it from disassembling and pouring its RNA content into the cell.

It is expected that other important animal viruses of similar structure viz, polio virus should also be known at the atomic level. The polio viruses existing in three known forms (sero types) are combatted by vaccines. Against the 89 different forms of cold viruses, it is however not possible to find an effective vaccine. It is fascinating to see how insight at the atomic level of viruses may provide clues on how to cure some of the commonest illnesses.

5. ACKNOWLEDGEMENTS

I wish to thank Erland Johansson, Börje Larsson, Pascale Larsson, William Mair, Bror Strandberg and Olle Sundberg for enlightening discussions on the subjects covered and for work on the manuscript. Information provided by Hans Lundqvist on the PET project and by Bo Sundqvist on the project Fast Ion desorption of biomolecules is gratefully acknowledged.

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REFERENCES


