Journal of Biological Physics and Chemistry, Vol 7, No 4, Dec 2007, pp153–158

23RA07F

The rôle of biology, physics and chemistry in human health

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Health is a perennially dominant preoccupation of man, and must have been so since the earliest days of his existence. One of the most ancient ritualized statements is "To your good health!", the literal equivalent of which can be found in almost every language ("Zum Wohl!", "Santé!", "Egészségére!", etc.), whenever glasses are raised and a toast is drunk at a social gathering. The Duke of Edinburgh, husband of Queen Elizabeth II of England, attributes his enduring good health to the innumerable such toasts drunk to him, even in absentia, as is the custom at a formal English banquet. Although in Georgia a whole string of toasts is typically drunk,[1] the toast to good health is considered to be among the most important; in other countries with a less developed tradition of toasting, it is typically the only one.

This preoccupation might, upon first consideration, appear to be superfluous. A living organism is healthy almost by definition—simply because the sick are less likely to survive, and in the long term therefore those prone to sickness are less likely to leave descendants, according to Darwin's principle. Health should therefore properly be seen as something privative, denoting the absence of ill-health.

The ability to survive in the face of environmental and social challenges is due to a highly evolved regulatory apparatus, with a tremendous repertoire of possible responses. Immediate, overwhelming dangers—volcanic eruptions, tsunamis—are best eliminated by fleeing. Since these are rare events, genetics can only play a very minor rôle in an organism's capacity to escape from such dangers. Another set of challenges—the attack of a wild animal, or a hostile human being—can be overcome by quick witted and decisive combat [1]. Here genetic endowment certainly plays a rôle, in determining key aspects of neural architecture and musculature. While death, the ultimate state of ill-health, is the usual outcome of a failure to respond satisfactorily to this kind of challenge, it is rarely considered in connexion with health. Besides, such attacks are not usually encountered in a modern civilized society.

Of far more relevance, today as throughout history, are accidents and (accidental) diseases. By accident I mean some event whose connexion with the volition of the victim is tenuous or nonexistent. It would include falling down a crevasse while traversing a glacier, or being struck by a rock falling from above, and, especially relevant in our technologically dense world, being knocked down by a motor-car, or poisoned by contaminated processed food. Propensity to be a victim of an accident can only be very weakly linked, if at all, to genetics, and hence would never be eliminated by a Darwinian selection mechanism. Therefore, one very important rôle of maintaining—or rather restoring—good health is countering the effects of accidents.

Infectious disease really falls into the same category. Human beings have a highly evolved immune system (as well as other defences) against invading microörganisms. Our environment is full of them, we are constantly breathing them in or otherwise ingesting them, and they are swiftly and effectively eliminated. But it can happen, perhaps in a moment of inattention, much as one could be electrocuted when using some faultily wired domestic apparatus, that one ingests some food riddled with pathogenic microörganisms (a hen's egg contaminated with salmonella, for example), the vast number of which overwhelms our defences, and only a swift and appropriate treatment with antibiotics can avert a fatal outcome.

What has now become a veritable healthcare industry originated in the necessity of combating the effects of accidents. There was a clear and rational benefit in doing so. An otherwise healthy and genetically sound individual, in which much effort and energy had been invested in order to bring successfully to adulthood, could not be allowed simply to be eliminated through some quirk of fate. The cost to society would have been too great. Notice that this principle remains valid at whatever level we consider, whether that of individuals, isolated families, or tribes, or nations, or the whole world—the World Health Organization plays a not insignificant rôle in maintaining health today. In the very early days of human society, when the exigencies of sheer survival through assuring the supply of food were dominant, it was quite natural that expertise in maintaining health—which, as we have pointed out above, consisted

[1] The first toast is to the gathering and to the reason for it; the second is to parents, for their long lives and to the memory of those who have departed; the third is to children, representing the new generation for life's continuation; the fourth is to the ladies sitting at the table; and so on.

Journal of Biological Physics and Chemistry **7** (2007) 153–158
Received 14 August 2007; *accepted* 4 December 2007

primarily in combating ill-health, i.e. maintaining health in a privative sense—was concentrated in a small number, perhaps only one or two per tribe, of specialists (often dubbed, rather depreciatingly, although we know very little about what they actually knew, "witch doctors"). Otherwise, in the absence of physical accidents or accidental infection, everyone would have remained in good health quite naturally, since all those factors that are considered to be important—plenty of exercise, fresh air, sunshine, mental challenges—were available in abundance.

Even in the early days of Stone Age civilization, the introduction of technology would have increased the likelihood of an accident. An axe could strike a limb instead of a log. A tree, suddenly felled, could inadvertently strike a fellow. Perhaps with the increased efficiency of food gathering there would have been a temptation to store a supply of food that should have been eaten fresh for a day or two—giving time for microörganisms to multiply. Such dangers have been vastly multiplied in modern, post-Industrial Revolution society.

Another significant source of disease is the congenital defect. The reason why these have not long been eliminated by Darwinian selection lies in the rather obvious fact that fitness is strictly context-dependent. The many genetic diseases that persist in a modern human society must presumably confer some advantages as well as disadvantages. A straightforward example is the single amino acid mutation in haemoglobin that gives rise to sickle cell anaemia. It is well known that the carriers of this gene are more resistant against malaria than those lacking it. Therefore, it is no surprise that this illness persists in malarial regions of the world. Modern civilizations, with their innumerable and subtle niches, provide very many opportunities for what appear to be defective genes to survive. Now that modern medicine has become so sophisticated in combating a tremendous variety of diseases, they are even more likely to survive in the future.

Public health institutions are a natural development of the concentration of expertise in the tribal witch doctor. The emergence of towns and cities gave rise to hospitals—therefore not only expertise, but also capital to provide for facilities had to be concentrated. And as expertise had to expand to follow the expansion of knowledge, it also began to comprise the institutionalized training of doctors. Some of the earliest European universities, such as Montpellier, were based on medicine. It was clearly a competitive advantage for a nation, vis-à-vis other nations, to possess the means for effective healthcare. This is perhaps most obvious in the military sphere—and some of the earliest hospitals were military ones: it was worth "repairing" a highly trained soldier so that he could return to combat, and society doubtless also felt a collective moral duty to care for those wounded through defending the state. And most of Europe had witnessed first-hand the devastating effects of ineffectually controlled infectious disease in times of plague.

What did healthcare look like 500 years ago? The treatment of the ghastly wounds inflicted by mediaeval warfare was a major part of it. Hohenheim (Paracelsus) introduced the cardinal principle that the wound had to be kept clean. Modern antibiotics merely build on that precept. Other innovations, such as the acceleration of healing, and scarless healing, are merely cosmetic. Paracelsus also insisted on the importance of a doctor caring for the whole patient, not just for the diseased or wounded organ or limb. Amputation is a psychological loss, as well as a physical one—a conviction amply supported by modern neurology.

Progressive cities employed a Chief Medical Officer, or Surgeon General.[2] As well as dealing with general matters of public health, that might be better described as public hygiene (i.e. connected with the supply of good quality drinking water, and the proper disposal of waste), he (or she—medicine was a popular profession among women in the Middle Ages, and many university professors in the medical faculties were women) also had to deal with social corruption, such as the widespread practice of doctors prescribing unnecessary medicines for the benefit of pharmacists [2]. This has a modern ring to it.

The rise of industrialized societies, and inter-national competition, provided a field rich in multiobjective optimization problems. Health and healthcare became significant economic factors. The general health of citizens is seen by governments as an important element in positioning the country in the international league tables. The UK government's chief scientist, Sir David King, has recently pronounced obesity as an even more pressing problem than global warming [3]. Whereas most European countries have seen heavy engineering industry and the mass production of consumer goods move to the Far East, especially China, the European pharmaceutical industry remains strong. In fact, to generate net export income, a country might very usefully promote good health through a healthy lifestyle for its own citizens, but through medication supplied by its own pharmaceutical industry for all other countries. (Such a policy would,

[2] Paracelsus himself occupied such a post (Stadtarzt) in Basel in the early 16th century.

however, nowadays be vitiated by the fact that the really big pharmaceutical companies are essentially all multinational ones.) An example of exporting drugs to generate income from, and ill health in, the importing nation is provided by Britain's exports of opium to China in the early 19th century, a policy that led to the Opium Wars, morally one of the shabbiest episodes of British history, and the ceding of the territory of Hong Kong to Britain.

The scientific basis of medicine

Medicine obviously started as a purely empirical business—certain plants, minerals and procedures were found to be effective. Presumably those members of the early tribes who were selected to become their witch doctors had a sharp eye and retentive memory for such things. A very curious feature of the early accumulation of knowledge, that persisted at least up until the end of the Middle Ages, was the retention of many erroneous ideas. Darwinian selection was certainly not operating here, since the ineffectuality of these erroneous treatments would have been obvious every time they were applied! Paracelsus was a pioneer in insisting on the importance of the direct experience of the physician in assessing the effectiveness of a particular treatment, rather than referring to the classics of Galen and Avicenna, among others [2]. For this insistence, especially when it was reinforced by the demonstrative burning of the offending books in the Basel marketplace, he made himself very unpopular among the then medical establishment. Paracelsus' start on putting medicine on a proper empirical basis was followed by other luminaries working in Basel, notably Vesal (anatomy) and Platter (pathology) among others. As well as acquiring a wealth of empirical (i.e., unconditional) knowledge, these physicians also began to create a real science in the shape of concepts and theories (i.e., conditional knowledge). An early example of that would be Paracelsus' system of seven "elements", comprising the earth, air, fire and water of the early Greeks, and sulfur, mercury and salt, corresponding to covalent (van der Waals), metallic and ionic solids respectively (in other words, this was a system for classifying materials, not an early attempt at making a kind of periodic table).

Since then, the sciences of biology, chemistry and physics have generated vast accumulations of knowledge, much of which has naturally been pressed into the service of human health.

Technology and healthcare

The general development of civilization has been accompanied by the development of technology.[3] Modern healthcare is nowadays intimately associated with high technology. One needs only to think of the complicated organic molecules, whose affordable production depends on sophisticated chemical knowledge, and extremely complex instruments such as magnetic resonance images and X-ray tomographs, requiring not only great sophistication as regards their hardware, but also very advanced information processing software in order to make them useful tools.

Yet it is a kind of paradox that many of these medical advances are mainly required to treat ailments that are more or less directly engendered by technologies in daily use. Many physiological disorders are caused by a lack of vitamins—people spend too much time indoors, and do not get enough fresh food. While the invention of refrigeration technology is often hailed as an important contribution to modern society, by encouraging the lengthy storage of food, during which it almost inevitably degrades to a greater or lesser extent, it has also become a significant contributor to ill health. Nevertheless, purified vitamins and other nutritional supplements can be

[3] It is worth pointing out here that at least up to the 20th century, science was but rarely the cause of technology. Technologists had their own agendas for improving the human estate (remarkably often the initial motivation appears to have been provided by the desire to create some object of aesthetic value), and only later on were their creations investigated by scientists. For example, the entire science of thermodynamics was motivated by the technology of the steam engine, which was initially developed entirely empirically by engineers. To be sure, the exact knowledge embodied in thermodynamics was later used to refine the design of steam engines. It is, therefore, quite erroneous to talk about the "science base" and its economic value, as some governments are nowadays prone to do when attempting to justify spending taxation revenues on supporting public science. The luxury of scientific investigation is only possible when a portion of society's wealth is not required for sustaining itself. In fact, the first call on any such surplus wealth generated (by, for example, labour-saving technology) is to provide leisure and relaxation. A small portion of that leisure time can then be used for the refined luxury of philosophical inquiry into the nature of the world around us. Thus, far from being the "base" of technology, science is the apex of a mighty pyramid, and without wealth-generating technology is an unaffordable luxury.

This view might have to be somewhat modified in the light of 20th century developments. Certain significant industries, for example nuclear power generation, and agriculture based on genetically modified organisms (GMO), clearly emerged from theoretical and laboratory investigations undertaken by scientists. Curiously, these technologies tend to be very unpopular among the general public, perhaps because they have not emerged organically from their midst, as did, for example, inventions such as the steam engine and the even more popular internal combustion engine, in the form of the motor-car.

supplied by the modern chemical industry. The motor-car, another significant, and very popular, invention, encourages a lack of exercise. That is, perhaps, the most benign of its ill effects. When one considers the despoilation of the countryside through motorways, the enormous waste of electricity on lighting roads (even though motor-cars have their own headlamps!), and the enormous pollution caused by emissions from internal combustion engines, and indeed through the whole gasoline supply chain, it is difficult to find sufficient beneficial elements to set against these detrimental ones. Worst of all, the widespread use of the motor-car has promoted a reckless disregard for human life. The enormous number of fatalities on roads, many of which are of innocent pedestrians, has become blandly accepted by society, and the far greater number of injuries in itself requires the maintenance of a large healthcare industry.

The latest revolution, that of information technology, has promoted its own brand of detrimental consequences to health. Sedentary, rather immobile work, such as in front of a computer screen, is a major cause of ill health, especially diseases of the back. Yet the cure is very simple—it suffices to move at fairly frequent intervals, at least every 20 minutes. Researchers at the Swiss Federal Institute of Technology in Zurich have developed a "smart" vest that gives the wearer a signal when he or she has been sitting still for too long [4]. The inventors have reckoned that the Swiss government could provide one of these vests gratis to every inhabitant of the country, with a net financial benefit in terms of saved healthcare costs.[4]

Society and healthcare

The maintenance of health would appear to be an obvious goal of human regulatory systems. When we are tired, we sleep; when we are hungry, we eat; when we are thirsty, we drink. These would appear to be simple and obvious ways of avoiding certain types of ill health. But like many "explanations" of behaviour based on simple feedback, they are actually too simplistic to be correct, or even useful approximations. We are aware that we should move frequently, yet are so engrossed in staring at a computer screen that we fail to move. The exigencies of work may prevent sleep [5]: many road and industrial accidents are caused by driving or working with attention diminished by fatigue. Hence, even at an individual level, we apparently fail to regulate our behaviour in an optimal fashion. Nevertheless, the survival of the individual shows that the regulation is nevertheless in some way effective.

Collectively, society has also developed regulatory mechanisms for maintaining health, and surviving. Typically, the health of some members is sacrificed in order for that of others to be maintained. In earlier epochs, those whose health was sacrificed were slaves (who were not even considered to be part of society), captured during military campaigns against foreign nations (i.e., prisoners of war). Later on, the unpleasantness and health risks of certain types of work[5] were compensated by cash. This might be considered as quite an advanced form of social solidarity. Of course, ideally such types of work should not have to be done, and perhaps indeed one day they might be eliminated by developments in technology. But given that they are necessary, those doing them can be rewarded by cash, which will at least give them the means to alleviate some of the ill effects through medical technology and affordable luxury.[6] One notices however that in many contemporary societies a kind of social atavism has emerged, and one finds ill paid people doing unpleasant jobs, and conversely low risk activities are sometimes very lucrative.[7]

21st-century health challenges

The Internet. We are still in the era of the information revolution. This seems to impose a largely sedentary lifestyle upon society. Nevertheless, as already pointed out, technology has an answer [4], and perhaps significant improvement in the man-computer interface will change that imposition.

Travel. Demand for travel appears to be insatiable. It is now said to be not uncommon for Londoners to travel to New York for shopping, or for Bernese to go to Milan for an afternoon. The love of travelling to the tropics for vacations brings a very real threat of importing endemic tropical infectious diseases, whose microbes will doubtless be able to adapt to temperate climates, especially if they are becoming warmer.

Centralization of food production. The consequences of this have been appalling. Numerous veterinary

[4] A sedentary lifestyle would also appear to be an obvious contributor to obesity, although curiously the authors of the report cited earlier [3] are at pains to deny a direct link.

[5] Examples are astronauts, divers, refuse collectors, those working unsociable hours.

[6] This ethical principle could also apply to the entrepreneur, who lives under the shadow of constant stress from the commercial risk of his activities.

[7] The ultimate risk is of course taken by the soldier, who puts his life on the line, yet is traditionally poorly compensated financially. Perhaps this is because in a certain sense one cannot put a value on human life (apart from in an actuarial sense).

epidemics (such as recent outbreaks of foot and mouth disease in Britain) can be more or less directly traced to a policy which, over the last few decades, has led to greater and greater distances between the producer and the consumer. There is a huge number of collateral consequences, including toxic pesticide residues in food, despicable practices in animal husbandry [6], and the enormous loss in variety of comestible crops and consequent genetic impoverishment of the Earth's resources. Any centralized catering establishment (as opposed to food prepared from fresh ingredients at home) introduces certain risks; on the one hand, these risks can have a picturesque quality [7] and are probably harmless to anyone with a normally healthy immune system; on the other hand this trend has also led to a proliferation of the aesthetically sterile establishments of purveyors of low quality standardized food and drink, as epitomized by businesses such as McDonald's and Starbucks, with health risks that are as yet largely uninvestigated.

Pollution. Europe at any rate is making strenuous attempts to control this epiphenomenon of the industrial age (and, in view of the vast quantities of discarded personal computers and mobile telephones, of the information age as well). "Waste" is being ever more imaginatively, and profitably, recycled. In essence, this is exactly what the early proprietors of soda factories using the Leblanc process did: the highly polluting hydrochloric acid that was initially simply discharged via tall chimneys was quickly found to be a profitable, and easily recoverable, by-product—but not before several valleys had been denuded of vegetation, and the Alkali Inspectorate (in the UK) brought into being by the government to force the manufacturers to recover the acid.

Aging. This is the most universal form of ill health, and also the most enigmatic. While one can see in general terms the necessity for it,[8] such a general argument leaves many important details, such as mean lifespan for example, open.[9] Governments are typically nowadays concerned about the demographic implications because of what is, at root, a very trivial factor: the exhaustion of pension funds! This could doubtless be regulated by mere fiscal manipulation (of course, the practical implementation might encounter political difficulties, but none would be insuperable).

How to meet these challenges

Nanotechnology, which is billed as the basis of the next technological revolution, can potentially provide solutions to many of these impending problems. The potential contribution of nanotechnology to medicine rests on three pillars [8]:

- Biosensors for monitoring the state of the body
- Automated diagnosis of disease (using inputs from the biosensors)
- Personalized treatment (on the basis of the automated diagnosis).

Nanotechnology is contributing to biosensors (which, in a nutshell, are devices that can selectively capture disease biomarkers and quantify their presence) both through the development of sophisticated nanostructured materials for the selective capture, and through the development of sophisticated miniaturized transducers for detecting the presence of the captured biomarkers.

It is contributing to the automation of diagnosis through the development of ever more powerful information processors, in turn through the development of ever larger scale integration of circuits, enabled by the miniaturization of the circuit components. Essentially, the automation of diagnosis is a matter of pattern recognition, which is, as is well known, the most difficult task for an artificial computer to undertake (yet simple and natural for the human brain).

It is contributing to personalized treatment both by the increase of information processing power, as above, which in this case is used to generate an appropriate cocktail of drugs and dosage régimes, and through the development of miniature (nanoscale) chemical reactors for the affordable synthesis of small quantities of personalized drugs.

Interestingly, many researchers presently feel that the use of biosensors for self-assessment by patients is ethically unacceptable. This view is only coherent if one lacks confidence in the reliability of the outputs of the devices. Needless to say, their introduction for self-assessment implies that the devices are able to self-validate themselves as appropriate. Appropriate checks would be carried out throughout the entire process; the same biosensors could also determine whether the

[8] An immortal being that is also invincible could remain forever unique. In the absence of aging, but without invincibility, mortality could nevertheless arise through fatal accidents. Therefore, in order for a population to survive, there has to be some mechanism for renewal ("reproduction"), implying that the population will steadily increase, and that in a finite living space, the emergence of ever more offspring will therefore put increasing pressure on parents.

[9] There are many ways of regulating population. For example, reproductive capacity could diminish with increasing population density—this actually seems to be happening now, at least in many European countries. Or, offspring could engage their parents (or rival societies) in mortal combat to provide Lebensraum (the danger of this as a regulatory mechanism is that total annihilation of both sides could result).

administered treatment is effective in diminishing the biochemical symptoms, and if not, the treatment could be immediately terminated. The continuous, or quasi-continuous, monitoring of a great variety of biomarkers is one of the main advantages of the introduction of nanotechnology into medicine. When compared with the twice-yearly monitoring of a handful of substances carried in the blood, as is conventionally done at present, the advantages of the nanotechnological approach would appear to be overwhelming. Furthermore, it by no means precludes the continuation of personal consultations with a wise and experienced family doctor.

Nanotechnology is also anticipated to lead to incremental, but significant, improvements in technologies that are already under development. For example, limb replacement is becoming more and more effective and sophisticated, through the improvement of the actual materials employed, the construction of the interface with the bearer's nervous system, and the provision of local information processing within the limb. These developments have already inspired a vigorous debate on "transhumanism", the enhancement of human capabilities through artificial (but conceived and fabricated by humans) means [9, 10].

Conclusions

All these developments might be subsumed under the heading of the application of knowledge to health. What single factor prevents good health?—ignorance. There is nowadays frequent mention of the "knowledge-based economy", often rather loosely without troubling to define it carefully. If it is indeed more than an empty platitude, surely it means the consequential application of the sum of (reliable) human knowledge to solve human problems. Such application is by no means limited to technology, with which most of this article has been concerned. Since resources are never unlimited, a very important practical matter is to determine whether the (quantifiable) expenditure on a measure to increase health or, more generally, to reduce risk, is justified in terms of the benefits. In the past, it has been extraordinary difficult to quantify those benefits, especially when considering a variety of different sectors. Recently a new parameter, the J (judgment)-value, has been devised [11], which offers a transparent and practical method for doing precisely that. This is an excellent example of the knowledge-based economy at work, and hopefully it will be widely applied to rationally assess the potential benefit of a proposed measure, before enacting it (or not).

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Ramsden, Jeremy J.

2007

Jeremy J. Ramsden, The rôle of biology, physics and chemistry in human health, Journal of Biological Physics and Chemistry, Vol 7, No 4, Dec 2007, pp153–158

http://hdl.handle.net/1826/2526