PHYSICS FOR HEALTH

Ralph W. Assmann[1], Giulio Cerullo[2] and Felix Ritort[3] – DOI: https://doi.org/10.1051/epn/2022504

[1] DESY, Hamburg, Germany
[2] Dipartimento di Fisica, Politecnico di Milano, Piazza L. da Vinci 32, 20133 Milano, Italy
[3] Small Biosystems Laboratory, Condensed Matter Physics Department – Facultat de Física – Universitat de Barcelona, Spain

The fundamental research on the physics of elementary particles and nature's fundamental forces led to numerous spin-offs and has tremendously helped human well-being and health. This is the subject of Chapter 4 of the EPS Challenges for Physics.

▲ MRI scanning equipment ©iStockPhoto

Prime examples include the electron-based generation of X rays for medical imaging, the use of electrical shocks for treatment of heart arrhythmia, the exploitation of particle`s spin momenta for spin tomography (NMR) of patients and the application of particle beams for cancer treatment. Ten-thousands of lives are saved every year from use of those and other physical principles. A strong industry has developed in many countries, employing hundreds of thousands of physicists, engineers and technicians. Industry is designing, producing and deploying the technology that is based on advances in fundamental physics.

Major research centers have established and provide cutting-edge beams of particles and photons for medical and biological research, enabling major advances in the understanding of structural biology, medical processes, viruses, bacteria and possible therapies. Those research infrastructures serve tens of thousands of users every year and help them in their research. Modern hospitals are equipped with a large range of high technology machines that employ physics principles for performing high resolution medical imaging and powerful patient treatment. Professors and students at universities use even more powerful machines for conducting basic research in increasingly interdisciplinary fields like biophysics and robotics. New professions have developed involving physicists and reaching out to other domains. We mention the rapidly growing professions of radiologists, health physicists and biophysicists.

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▲ **FIG. 1:** Virtual Reality (VR), advanced user interfaces and telecommunications and robot technology combine to create an enhanced surgical experience.

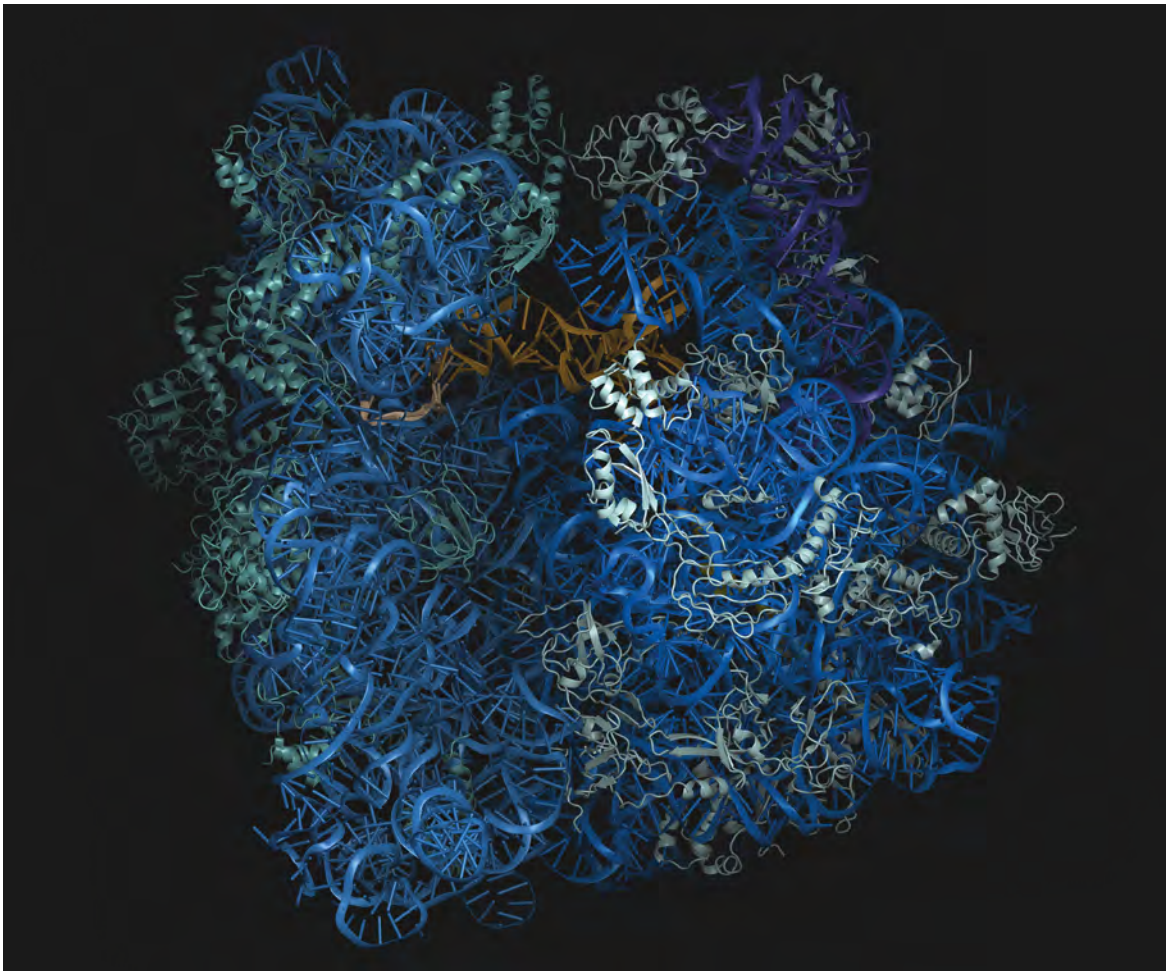
While physics spin-offs for health are being heavily exploited, physicists in fundamental research keep advancing their knowledge and insights on the biochemical mechanisms at the origin of diseases. New possibilities and ideas keep emerging, creating unique added value for society from fundamental physics research. Chapter 4 of the EPS Grand Challenges on physics for health does not aim to provide a full overview of the benefits of physics for health. Instead, the authors are concentrating on some of the hot topics in physics and health related research. The focus is put on new developments, possible new opportunities and the path to new applications in health.

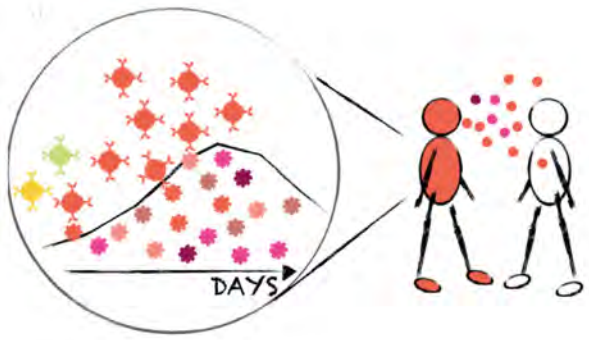
Using particle accelerators - Angeles Faus-Golfe and Andreas Peters describe the role of particle accelerators and the use of their beams for irradiating and destroying cancer cells. State of the art machines and possibilities for new irradiation principles, *i.e.* the FLASH effect, are introduced. As physics knowledge and technology advance, tumors can be irradiated more and more precisely, damage to neighboring tissue can be reduced and irradiation times can be shortened.

Using robotic systems - Darwin Caldwell looks at the promise and physics-based development of robotic systems in the macroscopic world, where they are complementing human activities in a number of tasks from diagnosis to therapy. Friedrich Simmel looks at the molecular and cell-scale world and explains how nanorobotics, biomolecular robotics and synthetic biology are emerging as additional tools for human health, for example as nano-carriers of medication that is delivered precisely [Fig. 1].

Using light - Henry Chapman and Jürgen Popp describe the benefits of light for health [Fig. 2]. Jürgen Popp is considering the use of lasers that have advanced tremendously in recent years in terms of power stability and wavelength tunability. Modern lasers are used in several crucial roles in cell imaging, disease diagnosis

▸ **FIG. 2:** The molecular structure of the ribosome, as determined by X-ray crystallography at DESY in Hamburg, showed researchers how this complicated nano-machine synthesises new proteins by reading genetic information encoded in messenger RNA molecules.





▲ **FIG. 3:** Within an infected host the cells of the immune system target existing viruses (and pathogens in general) by binding and neutralizing them. Each host has a vast repertoire of immune cells (denoted by different colors) from which those that best target the infection are chosen (same color as the viral strains). In some cases, these cells can further somatically evolve to increase their recognition power.

and precision surgery. Henry Chapman considers the use of free-electron lasers for understanding features and processes in structural biology. He shows that the advance of those electron accelerator-based machines has allowed a tremendous progress in the determination of the structures of biomolecules and the understanding of their function.

Pandemics - Aleksandra Walczak, Chiara Poletto, Thierry Mora and Marta Sales describe Physics research against pandemics, a multidisciplinary problem at the crossing of immunology, evolutionary biology and networks science. Pandemics is also a multi scales problem at the spatial and temporal levels: from the small pathogen to the large organism; and from the infective process at cellular scale (hours) to its propagation community-wide (months) [Fig. 3]. Simple mathematical models such as SIR (Susceptible-Infected-Recovered) have been a source of inspiration for physicists who model key quantities at an epidemic outbreak, such as the effective reproductive number R, in situations where a disease has already spread. A prominent example is the recent COVID-19 pandemics that has been more than a health and economic crisis. It illustrates our vulnerability where interdisciplinary & multilateral science play a crucial role to address a global challenge that is affecting societies at their core.

Outlook - Promise and progress in further diagnostics and therapies is also considered. Lucio Rossi explains the progress in magnetic field strength as it can be achieved with super-conducting magnets, while Marco Durante discusses the progress in charged particle therapy for medical physics.

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