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Introduction: Physics, Technology, and Technics during the Interwar Period

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Historians, philosophers, and physicists portray the 1920s and 1930s as a period of major theoretical breakthrough in physics, quantum mechanics, which led to the expansion of physics into the core of the atom and the growth and strengthening of the discipline. These important developments in scientific inquiry into the micro-world and light have turned historical attention away from other significant historical processes and from other equally important causes for the expansion of physics. World War II, on the other hand, is often seen as the watershed moment when physics achieved new levels of social and technical engagement at a truly industrial scale. Historians have shown that military interests and government funding have shaped physics to unprecedented degree, and according to some, to the extent of discontinuity with earlier practices of research (Forman 1987; Kevles 1990; Kaiser 2002). In this vein, Stuart Leslie wrote, "Nothing in the prewar experience fully prepared academic scientists and their institutions for the scale and scope of a wartime mobilization that would transform the university, industry, and the federal government and their mutual interrelationships" (Leslie 1993, 6). While one can never be *fully* ready for novelties, the contributors to this issue show that developments in interwar physics did prepare participants for their cold war interactions with industry and government.

The articles in this issue, based on two workshops, shift the traditional narrative to various interwar sites of interaction between physics research, technological questions, and technical instrumentations in the academy and in industry. They look at domains of engagement between physics and electrical engineering, fluid dynamics, technology, and economics. By pursuing these technical questions, it shows how industry, state agencies, and foundations were already playing a constitutive role in physics research during the interwar period. Prospects of improving useful devices and methods directed research into topics relevant for these technologies. The prospects of assisting technology of societal value was one of the important sources for the expansion of physics during the interwar period.

Although mutually influencing each other, physics, technology, and society are regarded as separate entities, which interact, shape each other, and sometimes also

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overlap. They are historical entities that evolved through a specific process, whose borders and properties continued to change also during the interwar period. These borders were sometimes blurred, and there were areas of overlap between them, but they still had distinct cores. For example, Rutherford's studies into the structure of the atom was clearly in physics, while his work on designing underwater microphones during World War I, was clearly a kind of engineering (Katzir 2012). The differences, we claim, are real ones, i.e., in the historical events that we study, while the distinction between the separate entities and the lines between them are analytical. As such they are not necessary, but they are useful for representing and understanding the historical events, i.e., the research and choices taken in the different fields. As with the dividing lines between colors, different observers may disagree where exactly to draw the lines, but we should agree that blue is distinct from green.

During the interwar period discussed here, physics was a well-established discipline, with a strong tradition, self-identity, and quite clear borders. In sociologists of science Anne Marcovich and Terry Shinn's terms, research in physics followed a disciplinary regime.

> The disciplinary regime is strongly defined by its self-referencing orientation. As regards research topics, they are drawn from within the discipline, and relate both to disciplinary history and inertia and to where disciplinary practitioners perceive the future of their discipline to lie. The discipline similarly sets its internal criteria for the evaluation of its research results. .. . The disciplinary regime itself constitutes its own market. Practitioners are the consumers of their own productions. Research output is directed to peer disciplinary colleagues. (Marcovich and Shinn 2012, 38–39)

Scientists choose research topics that extend active empirical and theoretical realms of research, explore related phenomena and variations on fruitful experiments (as judged within the discipline), raise the precision or the range of known empirical data, elucidate apparent anomalies and discoveries, and empirically test theories and conjectures.

The researchers discussed here, however, addressed not only questions set by the discipline, but also topics that were deemed useful for external groups. A central goal for these studies, set by various forces and agencies in society, was to improve practical devices and methods. Yet, these researchers did not engage directly with practical instruments (except for the case of the electron diffraction camera, discussed by Jaume Navarro), but rather extended relevant knowledge about natural phenomena. To assist the analysis of such activities we distinguish between "technics" (in plural) – as the tools and methods of their use (including "know-how") and "technology" – technology is propositional knowledge concerning technics. The sources of technology are wide ranging: from systematic data collected about the performance of the devices and methods used in practice, through their study and that of possible alternatives, to research into natural phenomena related to the technics used and scientific knowledge about them. In the twentieth century, technology was often very close to and interacted

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with the natural sciences (as in the examples of electronics and aerodynamics discussed here). The distinction between technics and technology is similar to the one in German between *Technik* and *Technologie*, which virtually disappeared in English, although dictionaries still mention "technics." The German term was also a source for Lewis Mumford's use of "technics" in his famous *Technics and Civilization* of 1934 (discussed by Staley in this issue). Similar to its use here, he preferred "technics" as a more concrete term than "technology." Although it helped Mumford to stress the crucial role of tools already before the industrial revolution, he applied the term also for the "modern technics" of his time (which is the period discussed in this issue), as done here. Mumford, however, did not employ the term to distinguish between systematic knowledge and tools as I suggest (Mumford 1946; Williams 2002).[1]

Technology, like science, includes theory and empirical findings. Research engineers, who carry out much of its development, conduct their own original research.[2] Despite some differences in attitude, scientists and engineers use mainly the same research methods. The main difference between their endeavors, claim historians of technology Edwin Layton and Walter Vincenti, is found in their goals. Technological (or engineering) research aims at providing useful information for practical technical design (Layton 1987; Vincenti 1990).[3] Its goals are, thus, set by considerations external to the structure of knowledge of the field. Turbulence, for example, became a central subject for fluid dynamics not because of internal developments in hydrodynamics, but due to its importance for designing aircrafts. The distinction by goals rather than by methods fits quite well Shinn's analysis of research regimes. Disciplinary logic is characterized by topics and questions of research rather than by ways of studying them. In Shinn's terms, the study of turbulence followed "utilitarian" rather than the disciplinary logic of research. The perspectives advanced by the historians of technology and the concepts suggested by the sociologists of science can help us to distinguish science from technology, pace contrary claims that they are indissociable in one "technoscience." Deviations of scientists from topics and questions that stem from the inner logic of the discipline indicate an effect of external influences on their research. As exemplified in this issue, one does not need to enter scientists' inner

[1]Donald Cardwell advances a similar distinction, as he employs "technics" for tools and methods that are not based on systematic knowledge, and "technology" for those who are. Yet, For Cardwell technics consists of tools and methods before the development of systematic knowledge about them, while we define technics as tools and methods regardless of the existence of the systematic knowledge about them (Cardwell 2001, 4–6).

[2]In discussing engineering in the context of research and development and in comparing it to science, the literature virtually always refers to the small minority of engineers working at institutes of higher education and research laboratories rather than to the majority of shop-floor and maintenance engineers. I refer to the former as research engineers. For a critique of neglecting the work of most engineers, see (Edgerton 2011, xvii). Edgerton's emphasis on the importance of examining the uses of technics highlights a clear difference between the majority of engineers, who characteristically work to make devices and methods function properly, and scientists.

[3]There are some differences in their views, among others Vincenti points at a few characteristics of engineering thinking that differ from the common practices of scientists. These differences, however, are not important in this context.

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thoughts to identify such deviations. The deviations might originate from an interest (of the researcher or his supervisors) in providing tools for improving technics, from technological research according to Layton and Vincenti, or from other interests such as those of related disciplines. When the instruments and techniques become central in setting the research questions, scientists move from a disciplinary to the transverse regime of knowledge production, usually organized around a "research technology," i.e. technics that can be used to study various topics. Its own development occupies much of the researchers' attention, as in the case of the electron diffraction camera discussed by Navarro below (Shinn 2008).

We examine here cases where physicists followed not only the disciplinary logic, but also expectations of other groups that wanted to utilize their findings. In particular, we look at their interactions with interests of social groups in specific technical improvements, "technological interests" for brevity sake. Research in engineering almost by definition interacts with the reactions from the users of the technics that it studies. For example, aerodynamics did followed not only prior research or expectations for the future of the field, but also inputs and demands of those who designed and used airplanes. In most of the studies here, and in our earlier workshops, we examine how scientists coped with the tension between the different expectations of technical systems on the one hand and their disciplinary logic on the other.

In our studies, we regard technology as an independent endeavor, which requires its own research and development processes. Although some of the technological developments that we discuss enjoyed the findings in physics and further research in the field (e.g. crystal frequency control, electron diffraction camera) they should not be seen as simple applied-science. Our case studies defy any purported linear-model, according to which knowledge flows unidirectionally from basic ('pure') science to applied science and then to technology (Godin 2006). We demonstrate that knowledge flowed in both directions and that technology and technics influenced physics, while also showing concretely how physics contributed to the 'scientification' (i.e. the use of scientific methods and findings) of specific domains and provided tools for improving technics with more success in some cases than in others. The scientification of engineering made the boundaries between disciplines and sub-disciplines more flexible. Inner boundaries and those between physics and engineering changed over time. A move between physics and engineering was possible, among other causes, because science and academic engineering were both based on propositional knowledge, and since they often used the same objects, such as the piezoelectric resonator, which formed a kind of boundary object in the analysis suggested by Hong (1999).

The institutional settings of interwar science encouraged interactions between research in physics and technology. The view that research in science in general and in physics in particular could and should foster technology became more common at the time, both among policy makers (who had earlier often doubted the practical value of research) and among practicing scientists (who became more inclined to assist technology). Consequently, governments, public institutions, military arms, and

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commercial companies considerably extended their support of research institutions that were aimed, at least partly, to foster technology through a better interaction with science. The number of such research laboratories multiplied and existing ones expanded (Katzir 2017). Scientists on their part became more receptive to technological interests in choosing their research topics, also within the academia. The scientists discussed here worked in a wide range of institutions and occupied different positions from traditional university professorships to novel research positions in industrial laboratories through public institutions aimed to mediate between science and technology.

States founded institutions to facilitate an exchange between research in physics and technology in the belief that it would foster industrial growth. The earliest was the German Physikalisch-Technische Reichsanstalt, established in 1887 (Imperial institute for physics and technology) (Cahan 1989). The British National Physical Laboratory and the National Bureau of Standards of the United States followed the example in 1900 and 1901 (Moseley 1978; Cochrane 1976). During and after the war, other countries (like Japan discussed by Ito) established similar institutes. Physicists working at the three institutions, like their colleagues at the newly founded Physico-Technical Institute in Leningrad (LFTI) participated in research on piezoelectricity discussed in my article. The British and American institutions contributed also to the study of aerodynamics, discussed by Eckert. In this field, another kind of new institute was prominent – the Kaiser Wilhelm Institute for Fluid Dynamics. The institutes of the Kaiser Wilhelm Society were funded by the joint efforts of the public (local and federal governments), philanthropies and industry to carry out research without any teaching duties. Often the subject matter of these institutes was connected to technological interests of German manufacturer, like those of aviation. Still, it allowed a more fundamental research than facilities connected directly to governmental agencies. The institute of physical chemistry of the society showed a similar interest in advancing technics in the research towards better electrical insulators, as discussed by karl Hall at the workshops. The study of aerodynamics enjoyed also the support of a new trade institute, namely the Hamburgische Schiffbau-Versuchsanstalt GmbH (officially translated as "Hamburg Ship Model Basin") established in 1913 by shipping and shipbuilding companies and the state of Hamburg to advance research on ship design. A similar establishment, the Hertz institute for the study of oscillations, founded in the next decade by a collaboration of the state, university and private electrical companies supported research on related questions in piezoelectricity (my paper). Industry further supported research within academia with money, material and expertise, directing its researchers to areas relevant for its interests. The company Zeiss, for example, encouraged the study of particular topics in piezoelectricity at Jena University.

Industry, philanthropy, and the states also financed newly established research funds that played an important role in supporting scientific activity at the interwar period. These funds granted specific projects deemed worthy by their committees. Expected contributions to technology were often an advantage and sometimes a requirement for getting support, especially by institutions aimed at improving the

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exchange between research and practice like the German Helmholtz-Gesellschaft zur Förderung der physikalisch-technischen Forschung (Helmholtz society for promoting physical-technological research, established in 1920) (Kirchhoff 2003) and The British Department of Scientific and Industrial Research (established in 1916) (Clarke 2010). The two institutions supported research pertinent to technology in piezoelectricity. In other places Heilbron and Seidel (1989) and Aaserud (1990) showed that they directed research in nuclear physics to topics of possible benefit for medicine. Their effect on other fields requires further research.

The large corporations invested more money in their in-house research laboratories than in support of research at other places. Their employees, naturally, stood under pressure to make their results useful for the company. Yet, as Falk Müller shows in his study of AEG's research laboratory presented at our workshops, the roles of the scientist within the corporation were changing with time and were a subject for negotiation. The physicists in the company strove to be regarded both as scientists-producers of new knowledge and as contributors to the company's devices and methods. In examining the research at different institutions Navarro's and my contribution show that academic scientists shared with their colleagues in corporations an interest in improving useful technics. Still, the different institutional setting did influence the scientists' orientation towards research related to technology and towards their use for designing new devices and methods.

Historians have discussed the foundation and development of new departments dedicated to research and development in industrial corporations, insulated (in various degrees) from the production lines and testing. The first appeared within the German chemical industry, which pioneered in mobilizing scientific research for its business goals, in the late nineteenth century (Homburg 1992); in 1900 and 1911 American electric and telecommunication corporations – GE and AT&T established larger research laboratories, which studied questions related to physicists (Reich 1985; Hoddeson 1981). While only a few large companies established research laboratories before the First World War, their number rapidly expanded after the war. During the 1920s extant and new laboratories grew in size employing an increasing number of physicists, who formed a larger share of the physics community (Hounshell 1996). European companies beyond the chemical industry established new laboratories or expanded their small research units. Yet, historians have concentrated on the early phase of the research laboratory rather than on the interwar period and rarely looked beyond the USA.[4] Our studies go beyond this limited picture and examine the research in industrial laboratories in their second, "maturing" phase paying central attention to major German laboratories. We further suggest viewing them in a larger context of the other above-mentioned institutes that carried out research to help developing

[4]A few notable exceptions regarding the period include (Kline and Lassman 2005) and (Hounshell and Smith 1988, 98–326). Shapin (2008) also discusses this period but elaborates on the sociologists rather than the scientists in the laboratories. On industrial research laboratories in Europe, see (Schubert 1987; Boersma 2002; Vries 2005).

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technologies. While much of the research on the new technology-oriented laboratories explores their institutional history and the external pressures on them, we examine here the kind of research carried out at the different sites, which was often similar across institutional (Katzir, Navarro) and even political-economical borders.

Those who established the new research institutes believed that scientific research in general and physics in particular would prompt technological development. While civil servants, military officers and politicians often had general concerns about the development of industry and technology in their countries, corporate managers usually had specific aims in establishing independent departments for research and development. They were worried about particular technological problems central to their business strategy and about potential technical developments that threatened their dominance in the markets (Hounshell 1996; Dennis 1987; Reich 1985; Smith 1990).[5] Electron physics, for example, provided tools required in order to answer technical problems of major commercial and societal value like coast-to-coast telephony, the main reason for establishing independent research departments at AT&T (Reich 1985) (.) Research in physics proved indispensable for developing some technics like radio, telephony, ultrasonic detection, and even more efficient incandesces lamps, arguably an emblematic product of the professional independent inventor. The success of scientific knowledge and research methodology to cope with such problems might have contributed to the optimism among physicists about their ability to tackle also old problems.

The physics of electrons plays an important role in the contributions to this issue. It provided topics of interest for research in physics not only due to advances in knowledge of electron, structure of material etc., but also due to the centrality of the electrical and telecommunication industries in funding and directing research. Most of the central and larger industrial laboratories that studied physics were in these sectors (e.g. AT&T, GE, AEG, Siemens, Philips). Much related research was done in national and state laboratories, due to the importance of electric and electronic technics to the economy, the well-being of society, and the military. By exploring various ways by which interests in improving electric and electronic technics directed scientists to questions pertaining to useful applications we offer examples for the influence of societal powers on the study of physics.

The examples discussed in this issue, although far from comprehensive, indicate that through its interactions with industry, state agencies, and technology-oriented research institutions, the needs of users and developers of technics had already played a significant role in shaping research in physics during the interwar period. Further examples discussed in our workshops corroborate this conclusion. These included the study of electric insulators at the Kaiser Wilhelm Institute and of the Leningrad physico-technical institute (Karl Hall), electron-optics at AEG (Falk Müller) the study of

[5]After WWI, diversifying the products of the companies became another important reason for commercial investment in research.

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non-linear dynamics following its appearance in radio technology (Scott Walter; see also Israel 2004; Katzir 2016, 30–34) and the major effort in the study of thermal emanation of electrons (thermionics) underpinning crucial phenomena in electronic technics of vast interest to telecommunication corporations and the militaries (Yoel Bergman). Other studies revealed additional cases of directing research into questions pertinent to technological interests. Research in nuclear physics, from natural and artificial radio-activity (already before the war), to particle accelerators, addressed questions of interests to the medical and power electricity industries also when they diverted from the central disciplinary questions (Heilbron and Seidel 1989; Weiss 1999; Hughes 1998). Atmospheric electricity and the existence of the ionosphere were studied under the active encouragement of the radio industry and its users (Yeang 2013; Anduaga 2009). Oil and mining companies set priorities in the study of the earth's crustal layer (Anduaga 2015). Acoustics, and especially electro-acoustics, addressed topics pertinent to radio and the new mass media technics (Beyer 1999; Wittje 2016). Lowen (1991) showed how the collaboration with industry on the development of the microwave generator in the late 1930s prepared the physicists at Stanford university for their work with the American government after the war.

In many respects the development of the relationships between physics and technology continued pre-WWI patterns. Chemistry suggested a model for directing research into topics of technical interest. The new kinds of state and corporate institutes that fostered research relevant to problems in technology had originated before the war. Yet their expansion made them much more significant after WWI. The application of scientific research and knowledge to the development of war technics strengthened relationships between physics, engineering, industrial and state agencies. Consider, the way the piezoelectric sonar opened the way for the technical application of the phenomenon and its related studies (my paper), and the use of wind tunnels developed during the war that stimulated the expansion of the study of turbulence (Eckert's paper). As the airplane became used as a weapon in WW I, state and military funding of aeronautical research became the rule in many countries. Military arms showed also an interest in piezoelectric telecommunication technics. Nevertheless, they did not have a constitutive role in the period. In this aspect, the interwar differed from the cold war period, especially in the USA. Private corporations played a central role in directing research.[6] Contemporaries judged scientific research as essential to technological developments, but after the war they considered it most important for the industrial-economic struggle between nations (Katzir 2017). With the support of the state, research was carried out for the sake of national prowess more than military prowess. While it did not enjoy (and suffer) the same kind of military patronage of the cold-war era, the needs of commercial and public users and developers of technics had already shaped research in physics during the interwar period.

[6]The role of commercial companies resembles their strong current influence.

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