Engaging Science, Technology, and Society

THEMATIC COLLECTION: STANDARDS & THEIR CONTAINERS ORIGINAL RESEARCH ARTICLE

Laboratory Hosts:
Postcolonial Parasites, Growth Factors, and the Fabrication of a Molecular Gaze

CHARLES A. KOLLMER
CALIFORNIA INSTITUTE OF TECHNOLOGY
UNITED STATES

Abstract

From the final decades of the nineteenth century onward, physicians and scientists trained in Europe's colonial powers devoted considerable attention to the lives of parasitic organisms found in the bloodstreams of humans and other animal hosts. Initially, this work required direct access to blood freshly sampled from a host and was spurred by desires to reduce the incidence of so-called tropical diseases such as malaria and sleeping sickness, which were especially prevalent in parts of the world that European powers had claimed as colonies. Soon, noting the successes of bacteriologists in cultivating pathogenic bacteria in sterilized glass containers, some researchers set out to domesticate parasitic protozoa, as well. By the early twentieth century, these investigators had codified recipes for culturing a range of blood parasites, dramatically increasing the mobility of these organisms between colonial and metropolitan laboratories. This essay explores a handful of the many meanings that researchers attached to parasites *in vitro*. As pathogens, these organisms stubbornly confounded colonial campaigns to staunch their spread between human and animal hosts, yet as laboratory organisms, they posed timely and tractable intellectual puzzles, such as how molecularly defined nutrients functioned in the broader metabolic contexts of living cells. This essay traces a genealogy of experimental practices that gave rise to laboratory hosts. By mimicking or supplanting the functions of living hosts' bodies, laboratory hosts transformed blood parasites into experimental tools. In time, they additionally came to incorporate synthetic and manufactured ingredients, further alienating parasites from their former dependencies on hosts' blood. Through these nutritional negotiations, researchers reimagined specific biological relationships as generic chemical ones, thus rendering parasites viable models of metabolic processes unfolding in a great many living things. While eliciting skepticism from some commentators, such chemical views of nature's order grew enormously influential in midcentury biology and medicine. In examining a selection of the materials and techniques that made up laboratory hosts, this essay illuminates significant yet overlooked continuities between the practices of colonial era tropical medicine and postwar molecular life science.

Keywords

parasitism; microbial cultures; empire; industrialization; metabolism

To cite this article Kollmer, Charles A. 2024. "Laboratory Hosts: Postcolonial Parasites, Growth Factors, and the Fabrication of a Molecular Gaze." *Engaging Science, Technology, and Society* 10(1–2): 262–291. https://doi.org/10.17351/ests2023.1451.

To email contact Charles A. Kollmer: ckollmer@caltech.edu.

Introduction

Historically speaking, life science and biomedicine owe a great deal to parasites. While the term "parasite" was widely used in English from the sixteenth century onward to refer to "a person who lives at another's expense," it subsequently took on new meanings in scientific studies of associations between different kinds of living things (Sapp 1994). Botanists and zoologists in nineteenth-century Europe used the term within a constellation of novel concepts, including "symbiote" and "commensal," to characterize how different species benefited or suffered through intimate associations with one another (de Bary 1879; van Beneden 1878). Early exponents of this vocabulary noted, however, that distinctions between these categories were, in practice, frequently murky. As German botanist Anton de Bary explained to an audience of naturalists gathered in the city of Kassel, "According to circumstances, relationships between parasite and host are known to be extremely multifarious" (de Bary 1879, 6).[1] De Bary's trenchant observation resonates to this day. Indeed, as historian Michael Osborne has observed recently, parasites fascinatingly "complicate our notions of individuality, autonomy, and dependence" (Osborne 2017, 206).

During the final decades of the nineteenth century, experimental studies of parasites began to utilize innovative means to counteract such ambiguities. These techniques shifted the definition of parasitism, at least within the quotidian work of laboratory researchers, as an emerging class of investigators became increasingly invested in obtaining so-called "pure cultures" (Gradmann 2001). The cultivation of microbes in glass containers individuated these living things, literally and conceptually. Adopting techniques most famously promulgated by the acolytes of Prussian physician Robert Koch, researchers grew homogenous clusters of single kinds of organisms, referred to as "colonies," in sterilized glass containers of specially formulated, solidified growth media. This procedure generated abundant evidence with which to cleave the microscopic world into nameable species analogous to those of the plant and animal kingdoms (Mazumdar 1995, 15–103). At stake in these classificatory exercises was not just the place of microorganisms in nature's order but also the attribution of causal agency in the transmission of contagious diseases.

For growing numbers of physicians and medical researchers, diseases were then properly understood not through the subjective symptoms experienced by individual patients but through the scrutiny and manipulation of disembodied parasites (Gradmann 2009; Velmet 2020). Forms of biological variation persisted, captured, for instance, by the notion of "virulence," a measure of germs' malignancy, which might diminish or increase as investigators passaged pathogens among different media or experimental animals (Mendelsohn 2002). Nonetheless, culture techniques presented investigators with discrete organisms, excised from the contingencies of hosts' physiologies and thus far easier to manipulate and measure. By the mid-twentieth century, cultured parasites had become central to a wide variety of biological and medical fields. A robust body of historical scholarship has accordingly drawn attention to the fecundity of research on experimental parasites, highlighting, among others, twentieth-century studies of

[1] Translations, here and throughout, my own.

pathogenic bacteria, such as *Shigella* and pneumococci, as well as work on viruses, including tobacco mosaic virus, bacteriophages, and cancer viruses (Creager and Gaudillière 1996; Amsterdamska 1993; Creager 2002; Sankaran 2021; Yi 2008; Scheffler 2019).

As historian of science Mathias Grote has observed, despite occasional grumblings that their artificiality distorted traits manifested by microbes "in the wild," pure culture techniques sustained an enduring and remarkably stable infrastructure for the scientific study of microorganisms (Grote 2018). These encounters between human researchers and cultured microorganisms have long fascinated not only historians of science, technology, and medicine, but also science and technology studies (STS) scholars (see Velmet and Kirchhelle, 2024). These literatures have amply documented the lives of laboratory organisms and their crucial roles in the experimental practices of life scientists (Ankeny and Leonelli 2018). Repeatedly, they have highlighted standardization as a stabilizing force in scientific work. Agreement regarding the types of living things that should be studied and the methods proper to this study lent coherence to geographically dispersed research communities, providing assurance that participants were indeed looking at the "same thing" (Kohler 1994; Rader 2004; Kirk 2005; Bolman 2022). While affirming the importance of standardization to the consistency of scientific work, however, some scholars have emphasized not only the contingencies characteristic of this process but also the risks of its excesses (Kirk 2012). As STS scholars Adele Clarke and Joan Fujimura argued in a classic analysis of this tension, though research ventures required "the right tools for the job [. . . ,] 'tools,' 'jobs,' and the 'rightness' [were . . .] all situationally constructed" (Clarke and Fujimura 1992, 5). Indeed, while pure (or axenic) cultures constituted a persistent standard for studying microbial life, means and ends of cultivating microbes varied considerably and unpredictably.

The cultivation of microscopic parasites offers a remarkable case in point. These techniques facilitated global circuits of exchange, connecting the work of experts operating in a range of geographic and institutional contexts. That said, interconnectedness did not eradicate regional and institutional differences in microbe science. In several recent instances, scholars have drawn attention to varying scientific approaches to the study of microbial life, noting especially the differences exhibited between studies in imperial and metropolitan settings (Sasges 2021; Lee 2021; Velmet 2020). While their boosters thought of culture techniques as a rationalized method of "isolating" microbes from the complexity of the habitats in which they appeared, this achievement was only ever partial. As sociologist of science Bruno Latour observed in his canonical study of Pasteurian bacteriology—

> [t]he word "isolate" does not have any ontological sense. It does not trace a sacred boundary. If we speak of isolation, we must give that word as material a meaning as the fabrication of an isolate in fiber glass or double glazing (Latour 1988, 108–9).

Grown in otherwise sterile containers of artificial media, microbes continued to exhibit what historian of science Hannah Landecker has aptly called a "paradoxical historicity," insofar as the materials employed to decontextualize microbes were themselves artifacts of the industrial and colonial milieus in which microbe scientists pursued their work (Landecker 2016). Despite the apparent stability of glass containers and the organisms housed within them, techniques used to produce these cultures were in fact drivers of historic change. Availing themselves of these novel tools, researchers collected parasites across the shifting

geographies of European empires. These undertakings fundamentally altered biological relationships, replacing diets of hosts' body fluids with an array of novel ingredients produced by commercial manufacturers and benchtop chemists. The incorporation of new elements in the experimental cultivation of blood parasites thus reflected the changing material metabolisms of biological and medical research, in which pharmaceutical firms, food processors, and organic chemists provided artificial forms of sustenance to microbial specimens that traveled vast distances between institutionalized culture collections and distant laboratory spaces.

This essay sheds light on the contexts of microbes' ostensible decontextualization with a case study on the cultivation of blood parasites between the late nineteenth and mid-twentieth centuries. Over this period, domesticated parasites gradually took on new identities as exemplars with which researchers reasoned not only about the specificity of infectious diseases but also about broader biological principles. During the 1920s and '30s, parasites came to appear as individualized entities, defined not by their relationships to living hosts but through metabolic inadequacies divulged through cultivation experiments. In concocting chemically defined growth media, some researchers came to see parasitism, not just as an association between species, but as a failure of parasites to synthesize or freely obtain some molecular substance "essential" to their vital processes. The cultivation of parasites thus contributed to the fabrication of a "molecular gaze" characteristic of life science and biomedicine in the twentieth and twenty-first centuries, in which molecules became the dramatis personae in mechanistic explanations of biological phenomena transpiring far below the threshold of unaided perception (Kay 1993; Grote 2019; Myers 2015). The debts of this influential view of life to colonial science and medicine have thus far received scant scholarly attention.

The essay's narrative unfolds in three parts. The first part traces the development of technologies for containing protozoan blood parasites so that they could be transported between colonial and metropolitan spaces. Writings of prominent practitioners of tropical medicine, including Timothy Lewis in British India and Alphonse Laveran in French Algeria, reveal the extent to which researchers in colonial contexts emulated the practices of metropolitan bacteriology to sustain parasitic life forms outside of hosts' bodies. The successful cultivation of protozoan blood parasites in glass containers was foundational for the assembly of large, institutional collections, such as the cultures maintained in the Parisian Pasteur Institute, which consolidated specimens collected from around the globe. The second section explores how these collected cultures were used to new ends, as innovations in food manufacture and nutritional science spurred experiments designed to enumerate with chemical precision what different living things required in their diets. Researchers trained at the Pasteur Institute, including Édouard Chatton, André Lwoff, and Marguerite Lwoff, built on these biochemical approaches to study blood parasites with little regard for either their colonial provenance or their etiological agency. Rather, blood parasites became assays for analyzing their media's chemical composition, an exercise paralleled by chemists' and industrialists' efforts to disassemble foods into processed, purified commodities. A final section follows the Lwoffs in their travels between laboratories in Germany and England, where the couple exploited cultured blood parasites to visualize generic metabolic reactions taking place ubiquitously in living cells. As critically minded contemporaries such as Dutch microbiologist A. J. Kluyver pointed out, though alluring in its promises, the

clarity of this molecular gaze extended neither to the physiological complexity of multicellular bodies, nor the capacity of cultured microbes to vary in response to different culture conditions.

Containing Blood Parasites

Long before any attempted to cultivate parasites in glass containers, zoologists and physicians were well aware of the tendency of minute living things to reside within the bloodstreams of animal hosts (Farley 1992; Worboys 1983; Foster 1965). Scientific and medical interest in these organisms intensified, however, during the late nineteenth century, as expanding European empires wrestled with the high mortality of so-called "tropical diseases," and researchers deliberated the merits of germ theories in explaining the incidence of these and other maladies. While some historical accounts have insisted that tropical medicine and bacteriology were distinctive enterprises, each with its own institutional and conceptual basis, attention to culture techniques reveals substantive overlaps (Farley 1992). As germ theories and pure cultures became increasingly popular with European researchers invested in identifying potentially pathogenic bacteria, physicians working in colonial states in Africa and Asia adapted these resources to study diseases ascribed to protozoan pathogens, thus laying foundations for a global circulation of cultured parasites, which soon traveled far beyond the regions in which the diseases they caused were prevalent. Concurrently, the parasites themselves played a role in shaping culture techniques, as some took more readily than others to the artificial shelters that humans assembled (Kollmer 2022).

"The circulation may become a habitat of minute organisms belonging to either the animal or vegetable kingdom," noted Timothy Richards Lewis, a pathologist working for the Army Medical Department in British India in the late 1870s (Lewis 1879, 2). Lewis was one of a growing number of nineteenth-century researchers fascinated by microbes found in the circulatory systems of humans and other host species. The stakes of studying these creatures were palpable for Lewis, who noted in a report commissioned by India's colonial government that "no medical subject has occupied more attention than the relation which may possibly exist between living organisms in the blood and some of the most fatal diseases" (ibid., 1). Entitled "The Microscopic Organisms Found in the Blood of Man and Animals, and Their Relation to Disease," the report reflected how expert knowledge of certain diseases had become, to a growing extent, a matter of systematically classifying parasitic species that some researchers attributed etiological agency. Exercises in cultivation thus promised to clarify the origins of epidemics and the causes of contagions, appealing prospects even for skeptics of germ theories such as Lewis (Arnold 1993, 194).

Lewis's work, in particular his investigation in May 1877 of so-called "spirillum-fever of Bombay," provides a sense of how he and others studied blood parasites, an activity that at this time required intimate contact with hosts. In Lewis's investigation of the fever, he visited wards of a local hospital, where patients sought succor from a contagious and relapsing fever (Carter 1878). The patients, however, came and left the ward, taking the parasites they contained with them, and such discharges had thwarted Lewis's work in the past (Lewis 1872, 10). To retain microscopic specimens, Lewis treated freshly collected blood with acid vapors that froze blood cells and parasites in place (Lewis 1879, 49). Immobilized under glass slides by their exposure to the acid, the parasites became enduring and static specimens, permitting examination and comparison long after fever patients had departed from the ward. Lewis then used these preparations to produce microphotographs that were subsequently published, distributing the labor of taxonomic

identification between distant expert readers. This evidence featured prominently in debates as to whether "Bombay fever" was, in fact, the same condition as relapsing fevers documented in other famine-stricken parts of the world, as well as the extent to which famine caused their incidence (ibid., 51).

Dead specimens prepared from patients' blood were not the only means available for containing parasites. Researchers made use of a veritable menagerie of animals, including birds, fish, rodents, dogs, and ruminants. These animal hosts had the merit of being more manipulable containers than human patients (Li 2002, 214). Lewis's studies of Bombay fever animated parallel investigations of the blood of rats that he instructed his servants to catch (Lewis 1879, 64). Curiously, examinations of blood taken from the rats challenged any straightforward link between parasitism and disease. As Lewis reported, "The organs of some animals are almost never free from parasites. It would nevertheless be scarcely justifiable to pronounce such animals as diseased in the ordinary sense" (ibid., 59). While Lewis's interest in rat blood was initially motivated by the concurrent outbreak of fever in a local hospital ward, he found it necessary to pay a visit to the Indian Museum to consult a well-reputed naturalist. In this way, inquiries into the nature of parasitism linked multiple settings of scientific and medical inquiry, trafficking between clinics, laboratories, and museums, a variation on what historian Robert Kohler has called the "lab-field border" (Kohler 2002). Yet, cultivation of some parasites, especially animal-like protozoa, outside of their hosts, remained elusive. As Lewis reported a decade later—

> Attempts have been made to 'cultivate' them in plain water, in sugar and water, glycerine and water, and in salt and water, as, also, in the blood itself, both with and without the aid of an incubator. But I could not satisfy myself that they multiplied; on the contrary, they seemed to denigrate after removal from the animal hour by hour (Lewis 1888, 636).

Other colonial medical researchers shared Lewis's goal of technical control over blood parasites. In the 1880s, Alphonse Laveran, professor of medicine at the Parisian military hospital École du Val-de-Grâce, published an account of research he had undertaken during a journey to Algeria. Examining the blood of dozens of soldiers and military prisoners suffering from malarial fevers, Laveran routinely sighted "round and dark bodies" bordered by "a series of thin filaments that moved with great agility, possessing an incontestable living nature," which he believed responsible for the fevers (Laveran 1881, 6). Much ink has been spilled regarding priority disputes over the "discovery" of the role of bloodsucking insects in many protozoan parasites' life cycles and, thus, as vectors of contagion among humans (Nye and Gibson 1997; Guillemin 2002). More important for the purposes of this essay was the opportunism with which Laveran examined parasites removed from their hosts. While noting that, "from a medical point of view," the malaria parasite was "assuredly the most interesting" blood protozoa [*hématozoaire*], Laveran later turned his attention to the genus *Trypanosoma*, deeming these parasites "in effect much easier to study" (Laveran 1892). A paper published in 1892 included illustrations he had collated of the organisms' life cycles in the blood of birds, fish, and rodents (see figure 1). As research organisms, Laveran opined, trypanosomes had attractive attributes. Unlike the "sporozoans" that caused malaria, trypanosomes continued to live for some time after extraction from their hosts, suggesting the possibility of keeping these protozoa in a container of blood serum or injecting them into animals to produce experimental infections, much in the way that medical researchers had become accustomed to handling bacteria (ibid., 267).

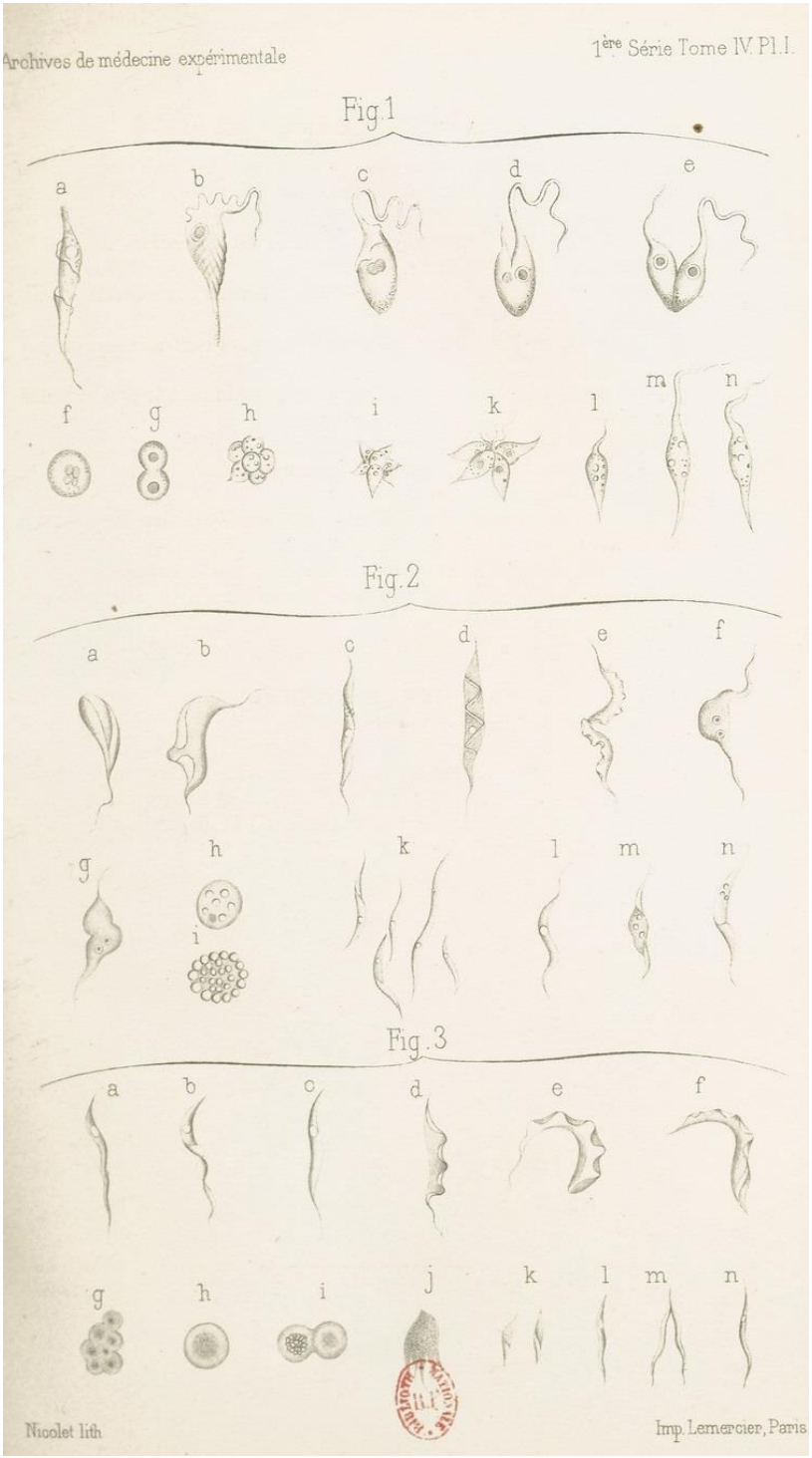

Figure 1. A figure that accompanied Alphonse Laveran's 1892 publication on trypanosomes observed in the blood of birds, fish, and rats (Source *Bibliothèque Nationale de France*, Public Domain, in Laveran 1892, 279).

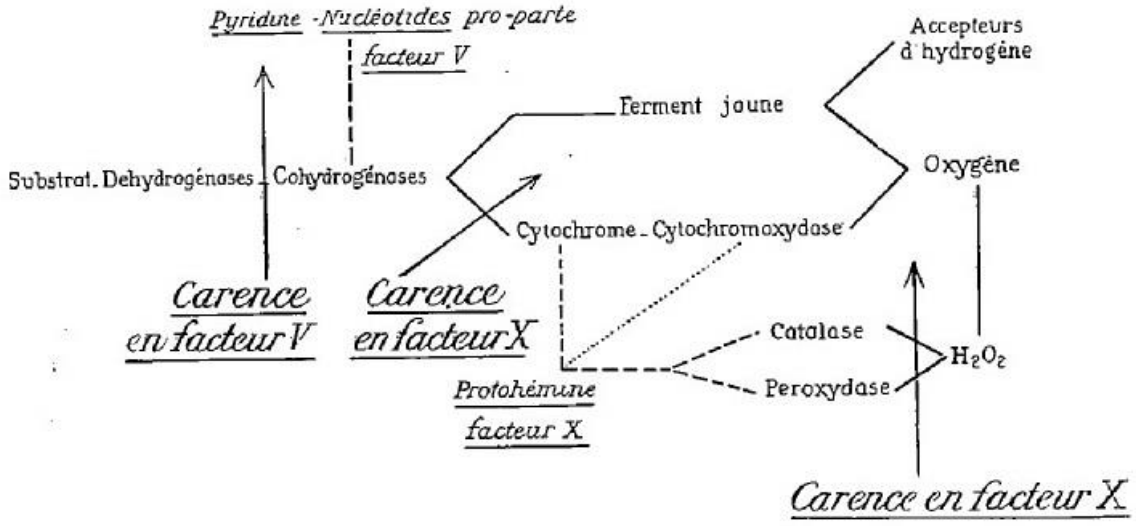

TABLEAU III. — Schéma de la respiration cellulaire d'après les travaux de Keilin, de Warburg et de Wieland (emprunté pour la plus grande partie à Keilin, 1933). Les relations des facteurs de croissance X et V avec les constituants des systèmes de catalyseurs-transporteurs sont indiquées en tirets. On a représenté par une ligne pointillée l'intervention hypothétique de la protohémine dans la constitution de la cytochromoxydase.
Les flèches marquent les points où la chaine de réactions est coupée en l'absence des facteurs X et V. Pour ce qui concerne l'action de la catalase et de la peroxydase, voir note, p. 135.
Erratum : Lire codéhydrogénases au lieu de cohydrogénases.

Figure 2. A schematic representation of the involvement of the "X" and "V" factors in aerobic cellular respiration based on the Lwoffs' examinations of blood parasites in Paris, Heidelberg, and Cambridge (Source *Bibliothèque Nationale de France*, Public Domain, in Lwoff and Lwoff 1937b, 134).

In the meantime, incremental successes in cultivating protozoan parasites depended on a long-established custom of instrumentalizing live animals as containers. For example, virtually all European research on nagana, an animal disease caused by a parasitic trypanosome, relied on a chain of artificial infections deriving from a dog that fell ill during a voyage from Zululand (then a British protectorate and now a part of South Africa) to England. After the ship arrived at its destination in November 1896, the dog was examined in the pathological laboratory of St. Bartholomew's Hospital in London before its eventual transfer to the University of Cambridge (Novy and McNeal 1904, 2; Kanthack, Durham, and Blandford 1899, 100). By 1903, blood containing the nagana parasite reached the opposite side of the Atlantic, as a Canadian physician on a fellowship to the Liverpool School of Tropical Medicine returned to North America with infected animals he had procured in England. The physician granted access to the animals to Frederick G. Novy and Ward J. McNeal, two researchers at the Hygienic Laboratory of the University of Michigan in Ann Arbor, who soon reported their successful cultivation of trypanosomes indefinitely "outside of the living body" in a medium

of the gelling agent agar and defibrinated rabbit blood (i.e., blood without the clotting protein fibrin) (Novy and McNeal 1904). The procedure resulted in a culture that Novy and McNeal kept alive for one hundred days. Sharing their method in print, they mused, "It seems as if the time is not far distant when most of the pathogenic protozoa will be cultivated and studied in our laboratories in the same way as is now done with bacteria" (ibid., 30).

This expectation was further borne out through the efforts of Charles Nicolle, director of the Pasteur Institute in Tunis (at this time a French protectorate) (Pelis 2006; Méthot 2019; Velmet 2020, 80–114). In 1908, Nicolle reported that he had modified Novy and McNeal's recipe to support *in vitro* cultures of *Leishmania tropicum*, organisms that caused so-called "Oriental sore" [*bouton d'Orient*] (now called cutaneous leishmaniasis) in human hosts. The protozoa had been "furnished by a black camel rider from the city of Tozeur in the region of Djerid who had contracted his malady in Tébessa in Algeria" (Nicolle 1908, 843). Describing the encounter for members of the French *Académie des sciences* and readers of its proceedings, Nicolle presented the man as little more than a convenient vessel of a taxonomically interesting specimen. Similar to the prose of other practitioners of tropical medicine, his scientific writing provided no indication of the pain or confusion the man may have experienced as Nicolle lanced his sores with a needle to extract the parasites beneath his skin (Lyons 1992, 76–101). The Novy-MacNeal-Nicolle (NNN) medium formulated to nourish the *Leishmania* taken from his lesions would become a standard tool of physicians and parasitologists for decades ("The Cultivation of Trypanosomes on Artificial Media" 1908; Thomson and Sinton 1912).

As researchers studied blood parasites, first in humans and other animals, then in glass containers, they altered the geographic distributions of these organisms, concentrating an otherwise impossible diversity of specimens in European culture collections. Such hoarding of specimens would long shape the institutional topography of biology and medicine (Kirchhelle and Kirchhelle 2024). As early as 1904, Laveran and Mesnil bragged that they had "succeeded in uniting in Paris at the Pasteur Institute a nearly complete collection of trypanosomes [. . .], not just in stained preparations, but in most cases still living" (Mesnil and Laveran 1904, viii). Like many doyens of tropical medicine, Laveran and Mesnil insisted that rigorous and comprehensive research was not possible in far-flung colonial laboratories but rather necessitated resources only available in industrialized European cities (Velmet 2020, 189–217). When Laveran received a Nobel Prize in 1907 "in recognition of his work on the role played by protozoa in causing diseases," he used the prize money to finance a department for studying "exotic pathologies" at the Pasteur Institute in Paris, and appointed Mesnil head of a new laboratory of protozoology, which housed a growing collection of cultivated blood parasites (Delaunay 1962, 130).

Their collection thrived in its metropolitan habitat. Indeed, throughout the early twentieth century, the lifeblood of the Parisian Pasteur Institute was, arguably, blood. Blood extracted from domesticated animals was indispensable for day-to-day work in many of the institute's laboratories, most conspicuously in the use of serum preparations as both diagnostics and therapeutics. The need for blood extended to the financial solvency of the institute as well, as it retained monopoly rights over the production of serotherapies (Gradmann 2008, 151). By 1895, these operations had reached such a scale that the institute began keeping horses in a former military stable a short rail journey from Paris. In a dedicated "bleeding room," technicians collected thousands of liters of blood annually to produce diphtheria antitoxin (Simon 2008). While much

animal blood flowed into the production of commodified therapeutics, a small portion of it also sustained a "live museum" of domesticated parasites (Strasser 2019, 29–66).

Much as historian Victoria Lee has shown was the case in imperial and postwar Japan, colonial culture collections housed in Europe informed the direction of further research throughout the twentieth century (Lee 2021). As will become clear, marked differences in the biological and geographic contexts in which researchers encountered parasites drove diverging intellectual agendas. On one hand, efforts to mitigate and treat parasitic infections continued apace (Neill 2009). On the other, the cultivation of parasites also raised questions as to why exactly some organisms lived off the blood of others. Key features of this project mirrored the increasingly processed diets of humans in the industrializing cultures of Europe's imperial states.

Growth Factors and Chemical Surrounds

During the 1920s and '30s in Europe and the United States, groups of researchers became invested in the identification and characterization of so-called "growth factors," a class of substances that certain organisms evidently needed to consume in minute quantities to survive. Growth factor researchers regarded nature's order through a molecular gaze, using the activities of laboratory organisms reared on chemically defined diets to envision metabolic reactions believed commonplace in living nature. Yet the generic language that researchers used to describe growth factors and biochemical pathways originated from idiosyncratic circumstances. On a practical level, much of it entailed the cultivation of microorganisms on specially formulated growth media. Parasitic specimens, readily available in the collections of medically oriented research institutions, such as the Pasteur Institute in Paris, featured prominently in such cultivation experiments. Techniques of containment and cultivation thus transmuted colonial parasites into cosmopolitan objects of inquiry. Culture media incorporated novel ingredients manufactured by metropolitan food and pharmaceutical firms, which processed heterogenous plant and animal matter into increasingly standardized commodities (Stoff 2012). In this respect, laboratory hosts incubated novel forms of postcolonial expertise by placing domesticated parasites in service of researchers, who sought to capture the vitality of living things in seemingly apolitical molecular structures and chemical pathways.

This project was on full display in June 1937, as a contingent of European researchers assembled at the Royal Society in London to discuss their work on growth factors. As one attendee explained the premise of the meeting for readers of the scientific weekly *Nature*:

> For a number of years, sporadic reports have been published by workers in the fermentation industries and bacteriology that the growth of yeast and bacteria depends not only on the provision in the diet of gross sources of energy and nitrogen, but also upon illusive materials—"bios," "accessory growth factors," akin to the "vitamins," responsible for the functioning of special phases of animal metabolism or even for the growth of animals. ("Growth Factors" 1937, 161).

The group gathered at the Royal Society was far from alone in its interest in food's "factors" and their alimentary significance for different living things. For upwards of a century, chemists and agronomists in Europe and North America had employed different means to study the constituent parts of foods. By feeding laboratory animals experimental diets, these researchers hoped to characterize chemical components of

food and their nutritive values (Carpenter 1994). These experimental studies of nutrition enumerated items consumed and excreted on "balance sheets," envisioning metabolism in terms of chemical inputs and outputs (Holmes 1987). At the same time, foods were subjected to novel manufacturing processes and consumed across geographically dispersed markets (Haushofer 2022). Chemical analysis and commodification were mutually reinforcing. This tendency was epitomized by novel products like Liebig's *Extract of Meat*, a substance manufactured at industrial scales by processing plentiful South American beef with imported machinery, heat, and pressure (Thudichum 1869). Producers exported the homogonous gravy that resulted, marketing it to European and American consumers as scientifically proven in its dietary merits (Finlay 1992).

By the beginning of the twentieth century, scientific study and industrial commodification had set the stage for an emerging body of expertise in so-called "food factors." The term itself was popularized by Cambridge University biochemist Frederick Gowland Hopkins, who used it to refer to ill-defined but evidently important components of a nourishing diet (Hopkins 1912; Kamminga and Weatherall 1996). The origins of Hopkins's coinage lay in his formulation of "synthetic" diets containing only purified proteins, fats, starches, sugars, and salts. The exercise demonstrated that young rats reared on such "artificial mixtures" did not grow and eventually died. Rather, for normal growth, the animals required small amounts of elusive substances present in rations of milk that Hopkins provided to a subset of the rats, an antecedent to the "vitamin," a concept coined a decade later (Funk 1914). These feeding experiments engendered what scholar Robyn Braun has aptly called "a conception of organisms that are dependent upon the external environment for the functions of regulatory processes maintaining their organization," thus breaking with nineteenth-century physiologist Claude Bernard's influential notion of a self-regulating *milieu intérieur* (Braun 2011, 485). Meanwhile, key elements of the external environments under study, namely, the cages of experimental animals and the foods that researchers provided them, were themselves altered by the industrialization and rationalization of food production. To conduct his feeding experiments at Cambridge, for instance, Hopkins availed himself of two commercial protein preparations, "Merck's pure casein" and a "commercial casein preparation known as 'Protene'" (Hopkins 1912, 428). With heat, acids, alkalis, or enzymes extracted from animal organs, industrial chemists and engineers decomposed plant and animal matter into partially digested proteins and purified amino acids, part of a broader phenomenon that geographer Nicholas Bauch has termed "the extensible digestive system" (Bauch 2017).

Hopkins' feeding experiments inspired subsequent nutritional studies of cultured protozoa, including blood parasites, undertaken by researchers in Felix Mesnil's professional ambit. In 1907, a recent graduate of the Sorbonne named Édouard Chatton began working at the Pasteur Institute in Mesnil's department of "Colonial Microbiology and Protistology" (Chatton 1938, 2; Jessus and Laudet 2020). While already enamored with the marine protozoa he had encountered during summer trips to the Arago Laboratory in Northern Catalonia, Chatton soon developed an intense interest in the activities of these organisms' parasitic counterparts. In 1913, he traveled to Tunisia to research *Leishmania* and the etiology of "Oriental sore," work he conducted under the supervision of Charles Nicolle (Chatton 1938, 30). Later, Chatton turned his attention to simplifying his culture techniques to feed blood parasites more efficiently (Chatton 1918). He discovered that he was not the only researcher interested in specifying what exactly protozoa required for life *in vitro*. Perusing a copy of the *Journal of Physiology*, he came across a report

authored by R. A. Peters, a fellow working in Hopkins's Biochemical Laboratory at the University of Cambridge. Peters's report asserted, "If growth will not proceed under the conditions of the experiments without the addition of a given substance, that substance may be considered to be essential" (Peters 1921, 13). This tautological reasoning was pervasive in experimental feeding studies, in which researchers used laboratory organisms as assays to ascertain the chemical conditions of their own existences. Reviewing Peter's work for a French readership, Chatton praised the enormity of its significance (Chatton 1921). In his view, pure cultures of protozoa grown on synthetic media represented powerful tools for clarifying the "power of synthesis of so-called heterotrophs," as well as the "nutritional dependencies of all living things," subjects of intense interest, especially for their implications for contemporaneous theorizations of the chemical evolution of plant and animal life (ibid., 848).

Chatton's premonitions sparked the ambitions of two young researchers studying zoology and medicine at the University of Paris. During the summer of 1921, while conducting research at the Roscoff Marine Station, Chatton met a first-year medical student named André Lwoff (Lwoff 1971, 3). Together, they examined a protozoon that they found nestled on the gills of a salt-water clam, carefully drawing the microbe's life cycle as it matured inside its bivalve host (Chatton and Lwoff 1921). Impressed, Chatton recommended Lwoff to Mesnil, who offered Lwoff a fellowship in his department. Here, Lwoff was charged with maintaining the cultures of parasites. One day, reading about culture techniques in the Pasteur Institute's library, Lwoff encountered Chatton's review on the "power of synthesis" exhibited by protozoa *in vitro* (Lwoff 2017, 50). This phrase itself became a mantra for Lwoff, a central thread in a line of research that occupied him for the next two decades. He began cultivating protozoa, not just for the purpose of maintaining the collection, but because he saw the exercise as a window into the fundamental chemistry of heterotrophy. Imitating the feeding trials conducted by Hopkins and others to determine the values of individual amino acids in the diets of laboratory animals, Lwoff cultivated free-living protozoa derived from infusions of hay procured from the Pasteur Institute's stable on minimal media (Lwoff 1923).

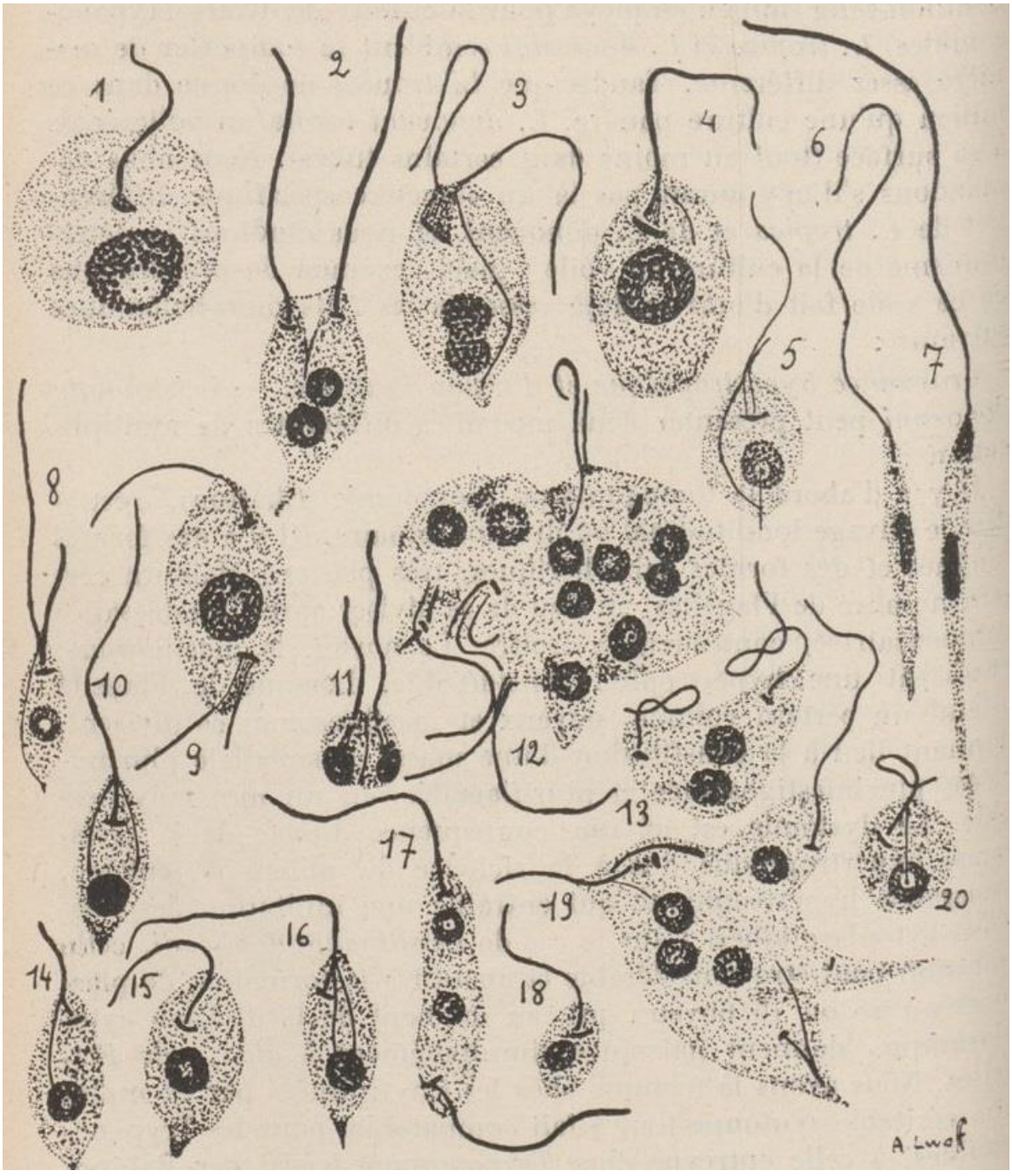

Figure 3. An illustration of *Leishmania donovani*, a protozoan parasite that caused the disease kala azar in its hosts (Source *Bibliothèque Nationale de France*, Public Domain, in Lwoff 1925, 162).

Blood parasites, too, were indispensable to this effort to measure the "power of synthesis" possessed by protozoa, especially after 1927, when Marguerite Lwoff, finished a degree in zoology at the University of Paris and received a fellowship to work in Mesnil's laboratory. Lwoff's spouse André Lwoff had already

conducted a study with two strains of *Leishmania* isolated in Tunis by Charles Nicolle and subsequently sent to Paris. In one strain, a change in the parasites diet from the NNN medium to a meat broth supplemented with fresh rabbit blood provoked a period of "hypertrophic growth" (see figure 3) (Lwoff 1925). Upon arriving at the Pasteur Institute, Marguerite Lwoff took custody of the parasites, probing variations in their nutritional needs. As she related in her first publication—

> . . . the majority of authors were only interested in establishing a culture medium more or less accommodating [to the parasites] without attempting to determine the necessity and role of each of its constituents. (Lwoff 1928)

To accomplish this latter aim, she substituted different brands of peptones for the nutrient broth and diluted the blood to its lowest possible concentration.

In her feeding trials, she worked primarily with several strains of *Leptomonas*, a group of flagellates that normally inhabited the digestive tracts of bloodsucking insects such as fleas and mosquitos, waiting to claim a portion of their hosts' next meal. Parasitologists had cultivated this genus for more than a decade because of its suspected role in the etiology of the deadly disease kala-azar (also known today as visceral leishmaniasis) (Wenyon 1914; Chatton 1919). Bracketing these clinical concerns, Marguerite Lwoff was drawn instead to *Leptomonas* after encountering a report on its tolerance for cultivation in highly diluted blood (Zotta 1923). Throughout the late 1920s and early '30s, Marguerite Lwoff tested the plasticity of parasites' requirements for blood, documenting its lower limits and comparing them to those of strains imported to Mesnil's laboratory in Paris by researchers travelling from Germany, North Africa, and the Americas. While the concentration of blood required for each strain ranged from one-part-per-five hundred to one-part-per-twenty thousand, the persistence of this need across her cultures suggested some key chemical difference between blood parasitism and other forms of heterotrophy.

A need for blood, she observed, was a dependency shared by other microorganisms, too (M. Lwoff 1931, 1234). Medical bacteriologists on both sides of the Atlantic had tinkered with media used to grow cultures of the bacterium *B. influenzae*, also known as "Pfeiffer's bacillus" (Fildes 1921; Thjötta 1921; Thjötta and Avery 1921). Following these researcher's examples, Marguerite Lwoff replaced the rabbit blood she customarily used to maintain the cultures with hematin, the pigment in hemoglobin responsible for blood's red color. She procured this substance from the German chemical company Merck (M. Lwoff 1931, 1235). Hundreds of miles from Paris, in a factory building in Darmstadt, technicians oversaw the decomposition of oxygenated horse blood with acids, yielding a dark crystalline substance that any researcher with a catalog of the company's products could order (Merck 1910, 138). Presiding over rows of test-tubes arrayed in Mesnil's laboratory, Marguerite Lwoff combined this substance with industrially digested peptones to assemble food she offered to domesticated parasites, organisms descended from forbearers that had travelled immense distances in the custody of itinerant physicians and zoologists. Through this elaborate arrangement of commodities and living things, Marguerite Lwoff provided parasitism a chemical definition, namely an inability to synthesize the very ingredients that she provided her protozoa.

The work of nutrition researchers in disassembling food into its factors reflected profound ontological shifts in living nature incurred in large part through the industrial manufacture of "whatever chemical products are to-day abjudged as being useful" (Merck 1889). Studies of microbial metabolisms

collided with the fast-changing, extracorporeal metabolisms of the food and drug industries, which furnished researchers with materials necessary for this dietary experimentation.

Essential Metabolites and Model Deficiencies

The blood arrived in Paris by plane in spring 1939. Prior to taking flight, it had circulated the bodies of Romanian peasants ill with pellagra. Each spring, inhabitants of small farming villages in rural Romania exhibited symptoms of the disease. Their skin inflamed, excrement watery, and minds addled, some came under the care of Leon Ballif, professor of medicine at the University of Iași and director of the university's psychiatric hospital. Ballif oversaw the collection of blood from his patients, enclosing with each samples a note tersely indicating the progress of the disease in the patient sampled (Ballif et al. 1939). Whisked to Paris via airmail, a service that recently had begun to move parcels throughout Europe's postal networks at the speed of flight, the blood and data arrived in the possession of André Lwoff, now head of the Department of Microbial Physiology at the Pasteur Institute in Paris (Allaz 2004, 10113; Rockefeller Archive Center (RAC) 1939). After inspecting the samples for signs of contamination, André Lwoff added minute quantities of the blood to flasks he had prepared, which contained a precise mixture of sterile chemicals, as well as a strain of bacteria belonging to the genus *Proteus*, derived from a culture maintained in the Pasteur Institute's extensive collection.

Recently, Lwoff had envisioned a protocol to use these bacteria as a measuring device. *Proteus* was incapable of growing in the absence of nicotinic acid (now called niacin or vitamin B3), a substance that a group of American physicians had recently shown to cure pellagra (Spies, Cooper, and Blankenhorn 1938; Spies, Bean, and Stone 1938; Fildes 1938). Because of its requirement for the very same nutrient that pellagra patients lacked, Lwoff speculated, the bacteria might serve as a diagnostic. Preliminary results showed a clear relationship between bacterial growth and concentrations of nicotinic acid in the bacteria's culture media (Lwoff and Querido 1938). By adding the blood of a patient suffering from pellagra-like symptoms to a culture of *Proteus*, Lwoff supposed, a physician might measure the severity of the patient's niacin deficiency. While few Parisians suffered from pellagra in 1939, it had been an acute concern for Romanian physicians for decades (Bărbulescu 2019, 146–72). Coordinating shipments of blood with Ballif, André Lwoff put the diagnostic to the test. This exercise, however, did not go according to plan. Puzzlingly, the growth of the bacteria indicated normal levels of nicotinic acid in the pellagrous patients' blood. Though diets deficient in the nutrient demonstrably caused the disease, this deficiency had no apparent consequences for the chemical composition of patients' blood, at least as far as could be told from the *Proteus* test. The use of bacteria as a diagnostic of pellagra was a failure.

This episode encapsulates both the promises and limitations of the molecular gaze achieved through chemical analysis of the nutritional needs of cultured microorganisms. Throughout the 1930s, the Lwoffs had engaged in comparative studies of parasitic and free-living protozoa, touting their approach as a way of precisely analyzing the biochemical activities of living cells. At the First International Congress of Microbiology, which took place between July 21 and 25, 1930 in Paris, André Lwoff presented the couple's work to a small group of visitors that gathered in Mesnil's laboratory (Dujarric de la Rivière, Plotz, and Gildemeister 1931). Moving from culture to culture, he explained to his audience the provenance of each strain and listed "substances indispensable to their growth and multiplication" (A. Lwoff 1931, 447). He

emphatically distinguished this undertaking from the work of physicians trained in tropical medicine earlier in the twentieth century. While these previous studies may have had "practical or historical importance, [. . .] the absence of an analysis of culture conditions" left them lacking in "precise facts" (ibid., 452). Consigning his scientific forebears to the dustbins of history, André Lwoff hoped to persuade his audience that, at its core, parasitism was a matter of molecules, not patients and their diseases.

This argument fell on receptive ears. In September 1932, André Lwoff met with Henry M. Miller, Assistant Director of the Natural Sciences Division at the Paris Office of the Rockefeller Foundation, an American philanthropic organization that frequently sponsored fellowships for European researchers, including the Lwoffs' erstwhile mentor Chatton (Kohler 1991; RAC 1932). With the foundation's blessing, the Lwoffs departed for Heidelberg, Germany, where they spent just over a year at the Kaiser Wilhelm Institute for Medical Research. The institute's director Otto Meyerhof was renowned for his work on the physiological processes taking place within living cells. In 1923, he had received a Nobel Prize for his studies on the formation of lactic acid in contracting muscle tissue, in which he had attributed the "source of muscular force" to a cyclic breakdown and synthesis of carbohydrates within muscle cells (Fruton 1999, 300; Surita 2022). Over the course of his career, Meyerhof opportunistically employed a range of laboratory preparations in his work on cellular metabolism, including sea urchin embryos, frog legs, and pigeon breasts (Schweiger 1985; Nachmansohn, Ochoa, and Lipmann 1952). Microbial cultures, especially cultured yeast, also aided his efforts to find chemical commonalities across cellular life forms. As he explained to an audience gathered to hear him speak in 1922 at the University of Cambridge, "[i]t may indeed be considered a success of general physiology and its mode of experimenting, that the chemical dynamics of a highly differentiated organ like the muscle could be partly revealed by the study of alcoholic fermentation of yeast" (Meyerhof 1924, 232).

When the Lwoffs arrived in Heidelberg, they brought with them the three strains of parasitic protozoa from the Pasteur Institute's collection that Marguerite Lwoff had found able to survive on trace amounts of blood (Lwoff 1934, 499). The media the couple used to analyze the parasites' needs also incorporated new ingredients. German chemists had recently synthesized many of the molecular components of hemoglobin from inorganic ingredients (Fischer and Zeile 1929). Through Meyerhof's contacts, the Lwoffs solicited samples of these synthetic substances, testing each one for its influence on the respiration and multiplication of their most sensitive parasite. One of the substances, a batch of protoporphyrin prepared by chemist Richard Kuhn, stimulated both vital processes in the protozoa. As André Lwoff reported on the couple's activities for a German scientific readership, he described protoporphyrin as "a substance that the flagellate cannot synthesize and is potent in very meager amounts. This is the definition of a vitamin" (Lwoff 1934, 517). He described this deficiency as the outcome of a "physiological evolution," a form of "degeneration" that had diminished the organisms' "power of synthesis [*Synthesefähigkeit*]," condemning it to a life of parasitism (ibid., 517). The elaborate artifice of Meyerhof's laboratory host thus opened windows onto otherwise irretrievable evolutionary pasts.

Departing Heidelberg a month prior to Adolf Hitler's ascension to Germany's chancellorship, the Lwoffs returned to Paris with their parasites. Their efforts in Germany were applauded by André Lwoff's contacts at the Rockefeller Foundation, who agreed to fund a second travel fellowship (RAC n.d.). This second trip brought the Lwoffs to the Department of Parasitology at the University of Cambridge in England. David Keilin, who directed the department, had spent much of his career documenting the adaptations of parasitic

insects and the role of hemoglobin in respiration (Radin 2017, 35–9; Mann 1964). In the 1920s, Keilin began to think of parasitism in relation to chemical reactions taking place in respiring cells. While studying the fly *Gasterophilus intestinalis*, whose larvae gestated in the stomachs of horses, he used a microspectroscope to check for spectral bands indicating the presence of hemoglobin across the different stages of the fly's life cycle. An examination of the thoracic muscles of adult flies divulged a striking pattern of bands. In a wide-ranging survey of bacteria, baker's yeast, animals, and plants, Keilin repeatedly found the same pattern, in which he saw evidence of the presence of a pigment he dubbed "cytochrome." Inadvertently, Keilin's fascination with the idiosyncrasies of one species of parasitic insect brought him into contact with a substance found virtually everywhere in living nature (Keilin 1925; Keilin and Keilin 1970).

While André Lwoff had told his funders at the Rockefeller Foundation that he would be studying "cytochrome and the respiration of free-living and parasitic protozoa," (RAC n.d.) the Lwoffs' plans changed. They began cultivating bacteria belonging to the genus *Haemophilus*, a group defined by its members' shared affinity for media containing hemoglobin (Bergey et al. 1923, 268). In correspondence with British researchers who had studied the nutrition of hemophilic bacteria in the 1920s, the Lwoffs acquired strains of *Haemophilus canis*, *influenzae*, and *parainfluenzae* from the National Collection of Type Cultures (Lwoff 1936; Lwoff and Lwoff 1936, 1937a; Knight 1971). The Medical Research Council, a British public funding agency, had sponsored the creation of this collection, which was in part modelled on the Parisian Pasteur Institute's successes in collecting and distributing "authentic strains of bacteria, protozoa, etc." across a network of scattered researchers (St. John-Brooks 1922). As the Lwoffs cultivated the hemophilic bacteria, they made use of purified cytochrome extracted from beef hearts, as well as chemical fractions of baker's yeast, itself produced in massive quantities by commercial manufacturers and simultaneously studied as the experimental organism of choice of countless biochemists (Gélinas 2010; Langer 2016). They tested the responsiveness of their parasites to the samples, finding it possible to specify that these organisms needed blood due to their inability to synthesize either hematin or another compound known as "codehydrogenase." This latter molecule was, according to the latest findings of German cell physiologists, "widespread in nature" and as essential to the respiration of animals as it was to the fermentation of yeasts (Warburg, Christian, and Griese 1935, 158).

In September 1937, André Lwoff attended a meeting at the Royal Society in London (see previous section), where he presented the implications of the work that he and Marguerite Lwoff had accomplished (Kögl et al. 1937). Lwoff offered the group a schematic representation of the syntheses taking place within respiring cells, as well as several breakpoints, where the absence of a specific "factor" interrupted the flow of chemical energy (see figure 2). These breakpoints used a handful of arrows to illustrate slight but decisive differences between the metabolisms of organisms beholden to consuming the blood of others and organisms without that obligation. Underlying what might have seemed a profound rift between the confines of parasitism and the freedom of heterotrophy, this picture indicated, there existed a common set of mechanisms comprising "cellular respiration," depicted here as a generic and universal process (Lwoff and Lwoff 1937b, 135).

This molecular view of life posited that cultured microbes might function as stand-ins, at least for the purposes of laboratory investigation, for all living cells. Yet some contemporaries were unconvinced that the complexity of metabolism could be so readily distilled to its chemical essences. When André Lwoff

presided over a discussion of "Nutritional Factors Associated with the Growth of Micro-Organisms" at the Second International Congress of Microbiology in 1936, the work elicited a cool assessment from microbiologist A. J. Kluyver, Chair of Microbiology at the Technical University of Delft, who suggested, "[i]t seems quite possible and even probable that some substance which is essential for the growth of a given microorganism in a special medium may be quite superfluous if the same organism is inoculated into a medium of quite different composition"(St. John-Brooks 1937, 443). Where the Lwoffs and others trafficked in chemical definitions of nutritional needs, Kluyver reminded them that the activities of cultured microorganisms were always mediated by the artifice of their containers.

Conclusions

None of the assorted blood parasites described in this essay achieved the popularity or status of mid-century model organisms like bacteriophage or *E. coli* (Summers 1999; Davis 2003; Kollmer 2020). They were not standardized models in this later sense but proofs of a larger concept that, in a state of domestication, parasitic life forms might be profitably instrumentalized to probe biological phenomena of general interest. As journalist Horace Freeland Judson described the arc of André Lwoff's early career: "Lwoff's discoveries of the thirties asserted the biochemical unity [. . .] of living things" (Judson 2013, 346). The nutrition of parasites, in other words, became epistemically useful for reasons uncoupled from their pathogenicity.

In the mid-twentieth century, André Lwoff achieved international renown for work on the life cycles of viruses, largely eclipsing both the role that Marguerite Lwoff had played in launching their careers, as well as the starting point of their shared interest in parasites in Mesnil's laboratory of colonial microbiology (Loison and Morange 2017; Harvey 2012). In the acceptance speech for the 1965 Nobel Prize that he shared with his mentees François Jacob and Jacques Monod for "discoveries on the genetic regulation of the synthesis of enzymes and viruses," André Lwoff explained his work on viral reproduction with a suggestive metaphor.

> An organism is a molecular society, and biological order is a kind of social order. . . . Viruses have not failed to follow the general law. They are strict parasites which, born of disorder, have created a very remarkable new order to ensure their own perpetuation (Lwoff 1977, 245).

For Lwoff, viruses qua parasites were illustrative of nature's order not because they caused pathologies but because their parasitism followed the same rules that structured the lives of uninfected cells. Reflecting on the standards and infrastructures on which Lwoff's scientific achievements relied, we might read his metaphor against its grain. Biological order was indeed a kind of social order, insofar as the techniques used to individuate parasites and the molecular constituent of their diets did not originate *de novo* but were borrowed from other domains of human culture, most conspicuously, the specimen collection practices of colonial biomedicine and the industrialization of food and drug production.

In its reconstruction of techniques for culturing blood parasites between the late-nineteenth and mid-twentieth centuries, this essay has illuminated continuities between two "revolutions," that historians of science and medicine have increasingly come to concur never happened. The first is the so-called "bacteriological revolution" of the late-nineteenth century. While novel techniques for handling microorganisms and germ theories of infection and fermentation multiplied, especially in the industrial

powers of Western Europe and regions across the globe these nations claimed as colonies, historians have pointed out both connections with earlier conceptual frameworks for making sense of fermentation and disease, as well as ways in which triumphalist rhetoric far outstripped the efficacy of these technical innovations (Barnes 2006; Gradmann 2009; Velmet 2020). The second is the "molecular revolution" of the mid-twentieth century. Here, historians have pointed out that the totemic powers of the double helix and the self-aggrandizing autobiographical accounts of researchers who came to identify as "molecular biologists" obscure a far subtler transformation of scientific concepts and practices (Abir-Am 1991; Creager 2010). Long before the canonical crystallographic study of the structure of DNA, physical and chemical sciences inspired a wide range of new approaches to the study of life and living nature (Wise 2018; Pauly 1987). Moreover, the uptake of molecular techniques and concepts across the life sciences and medicine was both gradual and diffuse (de Chadarevian and Kamminga 1998; Strasser 2006). As some commentators have pointed out, it is not a coincidence that historiographic emphasis on molecularity, especially the pronounced scholarly interest in the molecularization of genetics, coincided with the glut of funding and media attention garnered by research in genomics in the late twentieth and early twenty-first centuries (Strasser 2003).

A focus on the quotidian techniques used in scientific work can help scholars stretch the scale of the interpretations they offer (Landecker 2006; Grote 2018; Endersby 2009). By examining the materials and methods that sustained laboratory hosts and the blood parasites that inhabited them, this essay has situated a molecular "view from nowhere" in relation to circulating colonial biospecimens and technically reconfigured bits of organic matter. The use of parasites as laboratory organisms was ultimately, to riff on Claas and Charlotte Kirchhelle's work on phage surveillance (2024), a way of "seeing like a microbe," but rather than visualizing the incidence of infectious disease, investigators pieced together subcellular processes through dietary requirements for chemically defined "growth factors." Throughout these endeavors, the standardization of culture techniques and the contingency of their constituents stood in a tension that historian of science Hans-Jörg Rheinberger has identified as essential to the productivity of what researchers in the life sciences later came to call "experimental systems" (Rheinberger 1997).

The idea that paying attention to parasites might help us to better understand science as a dynamic cultural and historical phenomenon is not new. Michel Serres, poststructuralist philosopher and friend of Jacques Monod (Brown 2002, 23), once suggested that:

> . . . the parasite brings us into the vicinity of the simplest and most general operator on the variability of systems. . . . Is the parasite the element of metamorphosis (and by that old word I mean the transforming movement of life itself)? (Serres 2007, 191)

Serre's work was a key influence for Bruno Latour's subsequent account of Pasteurian bacteriology (Latour 1988, iv). Indeed, Latour suggestively linked microbiology to the vicissitudes of European empires, noting the "innumerable great missions of inquiry into ways of protecting parasites (white-skinned macroparasites) against parasites (microparasites in the form of miasmas or centers of infection)" (ibid., 95). It is the contention of this essay that scientific engagements with parasitism were equally central to a later landgrab, as mid-century molecular life scientists laid claims to intercellular territories.

Acknowledgements

The author would like to thank Claas Kirchhelle, Aro Velmet, Jacalyn Duffin, Matias Grote, Pierre-Olivier Méthot, Frédéric Vagneron, Jed Buchwald, two anonymous reviewers at ESTS, and members of the History of Science Program Seminar at Princeton University for invaluable comments on early versions of this material.

Author Biography

Charles A. Kollmer is Visitor in History at Caltech and History Faculty at an independent school in Los Angeles County.

References

Abir-Am, Pnina G. 1991. "Nobelesse Oblige: Lives of Molecular Biologists." *Isis* 82(2): 326–43. https://doi.org/10.1086/355756.

Allaz, Camille. 2004. *The History of Air Cargo and Airmail: From the 18th Century*. Translated by John M. Skilbeck. In association with the International Air Cargo Association. London: Christopher Foyle Publishing.

Amsterdamska, Olga. 1993. "From Pneumonia to DNA: The Research Career of Oswald T. Avery." *Historical Studies in the Physical and Biological Sciences* 24(1): 1–40. https://doi.org/10.2307/27757711.

Ankeny, Rachel A., and Sabina Leonelli. 2018. "Organisms in Experimental Research." In *Handbook of the Historiography of Biology*, edited by Michael Dietrich, Mark Borrello, and Oren Harman, 1–25. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-74456-8_15-1.

Arnold, David. 1993. *Colonizing the Body: State Medicine and Epidemic Disease in Nineteenth-Century India*. Berkeley: University of California Press.

Ballif, Leon, André Lwoff, Andries Querido, and I. Ornstein. 1939. "La nicotinamidémie chez les pellagreux [Nicotinamide in Pellagra Patients]." *Comptes rendus des séances de la Société de biologie et de ses filiales* [Reports of the Meetings of the Biology Society and Its Subsidiaries] 131(June): 903–7.

Bărbulescu, Constantin. 2019. *Physicians, Peasants, and Modern Medicine: Imagining Rurality in Romania, 1860–1910*. Budapest: Central European University Press.

Barnes, David S. 2006. *The Great Stink of Paris and the Nineteenth-Century Struggle against Filth and Germs*. Baltimore: Johns Hopkins University Press.

Bauch, Nicholas. 2017. *A Geography of Digestion: Biotechnology and the Kellogg Cereal Enterprise*. Oakland: University of California Press.

Bergey, David H., Francis C. Harrison, Robert S. Breed, Bernard W. Hammer et al. 1923. *Bergey's Manual of Determinative Bacteriology: A Key for the Identification of Organisms of the Class Schizomycetes*. Baltimore: Williams & Wilkins. https://wellcomelibrary.org/item/b29928655.

Bolman, Brad. 2022. "Dogs for Life: Beagles, Drugs, and Capital in the Twentieth Century." *Journal of the History of Biology* 55(1): 147–79. https://doi.org/10.1007/s10739-021-09649-2.

Braun, Robyn. 2011. "Accessory Food Factors: Understanding the Catalytic Function." *Journal of the History of Biology* 44(3): 483–504. https://doi.org/10.1007/s10739-010-9255-3.

Brown, Steven D. 2002. "Michel Serres: Science, Translation and the Logic of the Parasite." *Theory, Culture & Society* 19(3): 1–27. https://doi.org/10.1177/0263276402019003001.

Carpenter, Kenneth J. 1994. *Protein and Energy: A Study of Changing Ideas in Nutrition*. Cambridge, UK: Cambridge University Press.

Carter, H. Vandyke. 1878. "Notes on the Spirillum Fever of Bombay, 1877." *Medico-Chirurgical Transactions* 61: 273–301.

Chatton, Édouard. 1918. "La nutrition des flagellés intestinaux du genre Trichomastix en cultures pures. Simplifications rationnelles de la méthode de culture: les tissus coagules [Nutrition of Intestinal Flagellates of the Genus Trichomastix in Pure Cultures. Rational Simplifications of the Culture Method: Coagulated Tissues]." *Comptes rendus des séances de la Société de biologie et de ses filiales* [Reports of the Meetings of the Biology Society and Its Subsidiaries] 81: 774–77.

———. 1919. "Sur la culture pure d'un Leptomonas de la puce du chien et sur un caractère de ses formes culturales qui les distinguent de celles du Kala-Azar de souches humaine et canine [On the Pure Culture of a Leptomonas of the Dog Flea and on a Character of its Cultivated Forms that Distinguishes Them from Those of Human and Canine Strains of Kala-Azar]." *Bulletin de la Société de pathologie exotique* [Bulletin of the Society of Exotic Pathology] 12: 313–16.

———. 1921. "Review of The Substances Needed for the Growth of a Pure Culture of Coplidium Colpoda, by R. A. Peters." *Bulletin de l'Institut Pasteur* [Bulletin of the Pasteur Institute] 19:847–49.

———. 1938. *Titres et travaux scientifiques (1906–1937)* [Titles and Scientific Works (1906-1937)]. Sète: E. Sottano.

Chatton, Édouard, and André Lwoff. 1921. "Sur une famille nouvelle d'Acinétiens, les Sphénophryides, adaptés aux branchies des mollusques acéphales [On a New Family of Acinetians, the Sphenophryidae, Adapted to the Gills of Acephalous Molluscs]." *Comptes rendus hebdomadaires des séances de l'Académie des sciences [Weekly Reports of the Academy of Science]* 173(December): 1495–98.

Chadarevian, Soraya De, and Harmke Kamminga. 1998. *Molecularizing Biology and Medicine: New Practices and Alliances, 1910s–1970s*. Amsterdam: Harwood Academic Publishers.

Clarke, Adele E., and Joan H. Fujimura, eds. 1992. *The Right Tools for the Job: At Work in Twentieth-Century Life Sciences*. Princeton: Princeton University Press.

Creager, Angela N. H. 2002. *The Life of a Virus: Tobacco Mosaic Virus as an Experimental Model, 1930–1965*. Chicago: University of Chicago Press.

———. 2010. "The Paradox of the Phage Group: Essay Review." *Journal of the History of Biology* 43(1): 183–93. https://doi.org/10.1007/s10739-010-9226-8.

Creager, Angela N. H., and Jean-Paul Gaudillière. 1996. "Meanings in Search of Experiments and Vice-Versa: The Invention of Allosteric Regulation in Paris and Berkeley, 1959–1968." *Historical Studies*

in the Physical and Biological Sciences 27(1): 1–89. https://doi.org/10.2307/27757769.

Davis, Rowland H. 2003. *The Microbial Models of Molecular Biology: From Genes to Genomes*. New York: Oxford University Press.

De Bary, Anton. 1879. *Die Erscheinung der Symbiose: Vortrag gehalten auf der Versammlung Deutscher Naturforscher und Aerzte zu Cassel* [The Appearance of Symbiosis: Lecture Given at the Meeting of German Naturalists and Physicians of Kassel]. Strassburg: K. J. Trübner.

Delaunay, Albert. 1962. *L'Institut Pasteur: Des origines à aujourd'hui* [The Pasteur Institute: From its Origins to Today]. Paris: Éditions France-Empire.

Dujarric de la Rivière, René, Harry Plotz, and Eugen Gildemeister, eds. 1931. *1er Congrès international de microbiologie* [First International Congress of Microbiology]. Paris: Masson.

Endersby, Jim. 2009. *A Guinea Pig's History of Biology*. Cambridge, MA: Harvard University Press.

Farley, John. 1992. "Parasites and the Germ Theory of Disease." In *Framing Disease: Studies in Cultural History*, edited by Charles E. Rosenberg and Janet Lynne Golden, 34–49. New Brunswick, NJ: Rutgers University Press.

Fildes, Paul. 1921. "The Nature of the Effect of Blood-Pigment upon the Growth of B. Influenzæ." *British Journal of Experimental Pathology* 2(1): 16–25.

———. 1938. "The Growth of Proteus on Ammonium Lactate plus Nicotinic Acid." *British Journal of Experimental Pathology* 19(4): 239–44.

Finlay, Mark R. 1992. "Quackery and Cookery: Justus Von Liebig's Extract of Meat and the Theory of Nutrition in the Victorian Age." *Bulletin of the History of Medicine* 66(3): 404–18. http://www.jstor.org/stable/44442675.

Fischer, H., and K. Zeile. 1929. "Synthese des Hämatoporphyrins, Protoporphyrins und Hämins [Synthesis of Hematoporphyrin, protoporphyrin, and Hemin]." *Justus Liebigs Annalen der Chemie* [Justus Liebig's Annals of Chemistry] 468(1): 98–116. https://doi.org/10.1002/jlac.19294680104.

Foster, William D. 1965. *A History of Parasitology*. Edinburgh: Livingstone.

Fruton, Joseph S. 1999. *Proteins, Enzymes, Genes: The Interplay of Chemistry and Biology*. New Haven: Yale University Press.

Funk, Casimir. 1914. *Die Vitamine, ihre Bedeutung für die Physiologie und Pathologie mit besonderer Berücksichtigung der Avitaminosen: (Beriberi, Skorbut, Pellagra, Rachitis)* [The Vitamins and Their Significance for Physiology and Pathology with Particular Attention to Deficiencies: Beriberi, Scurvy, Pellagra, and Rickets]. Wiesbaden: J. F. Bergmann.

Gélinas, Pierre. 2010. "Mapping Early Patents on Baker's Yeast Manufacture." *Comprehensive Reviews in Food Science and Food Safety* 9(5): 483–97. https://doi.org/10.1111/j.1541-4337.2010.00122.x.

Gradmann, Christoph. 2001. "Isolation, Contamination, and Pure Culture: Monomorphism and Polymorphism of Pathogenic Micro-Organisms as Research Problem 1860–1880." *Perspectives on Science* 9(2): 147–72. https://doi.org/10.1162/106361401317447264.

———. 2008. "Locating Therapeutic Vaccines in Nineteenth-Century History." *Science in Context* 21(2): 145–60. https://doi.org/10.1017/S026988970800166X.

———. 2009. *Laboratory Disease: Robert Koch's Medical Bacteriology*. Translated by Elborg Forster. Baltimore, MD: Johns Hopkins University Press.

Grote, Mathias. 2018. "Petri Dish versus Winogradsky Column: A Longue Durée Perspective on Purity and Diversity in Microbiology, 1880s–1980s." *History and Philosophy of the Life Sciences* 40(1): 11–41. https://doi.org/10.1007/s40656-017-0175-9.

———. 2019. *Membranes to Molecular Machines: Active Matter and the Remaking of Life.* Chicago: University of Chicago Press.

"Growth Factors." 1937. *Nature 140*(3534): 161. https://doi.org/10.1038/140161a0.

Guillemin, Jeanne. 2002. "Choosing Scientific Patrimony: Sir Ronald Ross, Alphonse Laveran, and the Mosquito-Vector Hypothesis for Malaria." *Journal of the History of Medicine and Allied Sciences* 57(4): 385–409. https://doi.org/10.1093/jhmas/57.4.385.

Harvey, Joy. 2012. "The Mystery of the Nobel Laureate and His Vanishing Wife." In *For Better or for Worse? Collaborative Couples in the Sciences*, edited by Annette Lykknes, Donald Opitz, and Brigitte van Tiggelen, 57–77. Springer: Heidelberg..

Haushofer, Lisa. 2022. *Wonder Foods: The Science and Commerce of Nutrition*. Oakland: University of California Press.

Holmes, Frederic L. 1987. "The Intake-Output Method of Quantification in Physiology." *Historical Studies in the Physical and Biological Sciences* 17(2): 235–70. https://doi.org/10.2307/27757583.

Hopkins, F. Gowland. 1912. "Feeding Experiments Illustrating the Importance of Accessory Factors in Normal Dietaries." *The Journal of Physiology* 44(5–6): 425–60. https://doi.org/10.1113/jphysiol.1912.sp001524.

Jessus, Catherine, and Vincent Laudet. 2020. *Les vies minuscules d'Edouard Chatton* [The Miniscule Lives of Edouard Chatton]. Paris: CNRS.

Judson, Horace Freeland. 2013. *The Eighth Day of Creation: Makers of the Revolution in Biology* (Commemorative Edition). New York: Cold Spring Harbor Laboratory Press.

Kamminga, Harmke, and Mark W. Weatherall. 1996. "The Making of a Biochemist. I: Frederick Gowland Hopkins' Construction of Dynamic Biochemistry." *Medical History* 40(3): 269–92. https://doi.org/10.1017/S0025727300061305.

Kanthack, A. A., Herbert E. Durham, and W. F. H. Blandford. 1899. "On Nagana, or Tsetse Fly Disease. (Report, made to the Tsetse Fly Committee of the Royal Society, of Observations and Experiments Carried out from November 1896, to August 1898.)." *Proceedings of the Royal Society of London* 64(100–188): 100–118. https://doi.org/10.1098/rspl.1898.0074.

Kay, Lily E. 1993. *The Molecular Vision of Life: Caltech, the Rockefeller Foundation, and the Rise of the New Biology*. New York: Oxford University Press.

Keilin, David. 1925. "On Cytochrome, a Respiratory Pigment, Common to Animals, Yeast, and Higher Plants." *Proceedings of the Royal Society of London, B—Biological Sciences*, 98(690): 312–39. https://doi.org/10.1098/rspb.1925.0039.

Keilin, David, and for by publication by Joan Keilin. 1970. *The History of Cell Respiration and Cytochrome*. Cambridge, UK: Cambridge University Press.

Kirchhelle, Claas, and Charlotte Kirchhelle. 2024. "Northern Normal: Laboratory Networks, Microbial Culture Collections, and Taxonomies of Power (1939–2000)." Engaging Science, Technology, and Society 10(1–2): 292–336. https://doi.org/10.17351/ests2023.1445.

Kirk, Robert G. W. 2005. "Reliable Animals, Responsible Scientists: Constructing Standard Laboratory Animals in Britain c.1919–1976." Ph.D. diss., University of London. https://discovery.ucl.ac.uk/id/eprint/1445731/.

———. 2012. "'Standardization through Mechanization': Germ-Free Life and the Engineering of the Ideal Laboratory Animal." *Technology and Culture* 53(1): 61–93. https://doi.org/10.1353/tech.2012.0025.

Knight, Bert C. J. G. 1971. "On the Origins of 'Growth Factors.'" In *Of Microbes and Life*, edited by Jacques Monod and Ernest Borek, 16–18. New York: Columbia University Press.

Kögl, Fritz, Paul Gordon Fildes, Bert C. J. G. Knight, George Maxwell Richardson et al. 1937. "Discussion Meeting on Growth Factors." *Proceedings of the Royal Society of London, Series B—Biological Sciences*, 124(834): 1–13. https://doi.org/10.1098/rspb.1937.0068.

Kohler, Robert E. 1991. *Partners in Science: Foundations and Natural Scientists, 1900–1945*. Chicago: University of Chicago Press.

———. 1994. *Lords of the Fly: Drosophila Genetics and the Experimental Life*. Chicago: University of Chicago Press.

———. 2002. *Landscapes & Labscapes: Exploring the Lab-Field Border in Biology*. Chicago: University of Chicago Press.

Kollmer, Charles A. 2020. "From Elephant to Bacterium: Microbial Culture Techniques and Chemical Orders of Nature, 1875–1946." Ph.D. diss., Princeton, NJ: Princeton University. https://dataspace.princeton.edu/handle/88435/dsp01ww72bf58n.

———. 2022. "International Culture Collections and the Value of Microbial Life: Johanna Westerdijk's Fungi and Ernst Georg Pringsheim's Algae." *Journal of the History of Biology* 55(1): 59–87. https://doi.org/10.1007/s10739-022-09669-6.

Landecker, Hannah. 2006. *Culturing Life: How Cells Became Technologies*. Cambridge, MA: Harvard University Press.

———. 2016. "It is What it Eats: Chemically Defined Media and the History of Surrounds." *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*

57: 148–60.
https://doi.org/10.1016/j.shpsc.2016.02.004.

Langer, Erika Michelle. 2016. *Molecular Ferment: The Rise and Proliferation of Yeast Model Organism Research*. Ph.D. diss., University of California, San Francisco.

Latour, Bruno. 1988. *The Pasteurization of France*. Translated by Alan Sheridan and John Law. Cambridge, MA: Harvard University Press.

Laveran, Alphonse. 1881. *Nature parasitaire des accidents de l'impaludisme: description d'un nouveau parasite trouvé dans le sang des malades atteints de fièvre palustre* [The Parasitic Nature of Incidents of Malaria: Description of a Novel Parasite Found in the Blood of Patients Suffering from Malarial Fever]. Paris: Baillière.
https://archive.org/details/b21941518.

———. 1892. "Des trypanosomes parasites du sang [Parasitic Trypanosomes of the Blood]." *Archives de médecine expérimentale et d'anatomie pathologique* [Archives of Experimental Medicine and Pathological Anatomy] 4(6).
https://gallica.bnf.fr/ark:/12148/bpt6k9738292r/f267.

Lee, Victoria. 2021. *The Arts of the Microbial World: Fermentation Science in Twentieth-Century Japan*. Chicago: University of Chicago Press.

Lewis, Timothy R. 1872. *On a Hæmatozoon Inhabiting Human Blood: Its Relation to Chyluria and Other Diseases*. Calcutta: Office of the Superintendent of Government Printing.
https://wellcomecollection.org/works/mzbzd9h3/items.

———. 1879. *The Microscopic Organisms Found in the Blood of Man and Animals and Their Relation to Disease*. Calcutta: Office of the Superintendent of Government Printing.
http://archive.org/details/b22651494.

———. 1888. "Further Observations on Flagellated Organisms in the Blood of Animals." In *Physiological and Pathological Researches; Being a Reprint of the Principal Scientific Writings of the Late T. R. Lewis, M.B.*, edited by William Aitken, G. E. Dobson, and A. E. Brown, 630–8. London: Lewis Memorial Committee.

Li, Shang-Jen. 2002. "Natural History of Parasitic Disease: Patrick Manson's Philosophical Method." *Isis* 93(2): 206–28.
https://doi.org/10.1086/344961.

Loison, Laurent, and Michel Morange, eds. 2017. *L'invention de la régulation génétique: les Nobel 1965 (Jacob, Lwoff, Monod) et le modèle de l'opéron dans l'histoire de la biologie* [The Invention of Genetic Regulation: The 1965 Nobel Prize (Jacob, Lwoff, Monod) and the Operon Model in the History of Biology]. Paris: Rue d'Ulm.

Lwoff, André. 1923. "Sur la nutrition des Infusoires [On the Nutrition of Infusoria]." *Comptes rendus hebdomadaires des séances de l'Académie des sciences* [Weekly Reports of the Academy of Science] 176: 928–30.

———. 1925. "Croissance hypertrophique, division multiple et constitution de la cinétide de Leishmania donovani Lav. et Mesn., type infantum Ch. N. [Hypertrophic Growth, Multiple Division, and Kinetid

Formation of Leishmania donovani].” *Comptes rendus des séances de la Société de biologie et de ses filiales* [Reports of the Meetings of the Biology Society and Its Subsidiaries] 92: 160–63.

———. 1931. “Cultures de protistes libres et parasites [Cultures of Free and Parasitic Protists].” In *1er Congrès international de microbiologie* [First International Congress of Microbiology]. Paris 1930: documents recuellis et publiés, edited by R. Dujarric de la Rivière, Harry Plotz, and Eugen Gildemeister, 2: 447–52. Paris: Masson.

———. 1934. “Die Bedeutung des Blutfarbstoffes für die parasitischen Flagellaten [The Significance of Blood Pigment for Parasitic Flagellates].” *Zentralblatt für Bakteriologie, Parasitenkunde und Infektionskrankheiten [Central Journal of Bacteriology, Parasitology, and Infectious Diseases]* 130: 498–518.

———. 1936. “La fonction de la protohémine pour les protozoaires et les bactéries parahémotrophes [The Function of Protohemin for Parahemotrophic Protozoans and Bacteria].” *Comptes rendus des séances de la Société de biologie et de ses filiales* [Reports of the Meetings of the Biology Society and Its Subsidiaries] 122: 1041–42.

———. 1971. “Protozoa to Bacteria and Viruses - Fifty Years with Microbes.” *Annual Review of Microbiology* 25(1): 1–27. https://doi.org/10.1146/annurev.mi.25.100171.000245.

———. 1977. “Interaction among Virus, Cell, and Organism.” In *Nobel Lectures in Molecular Biology: 1933–1975*, edited by David Baltimore, 245–56. New York: Elsevier.

———. 2017. *André Lwoff, Une autobiographie: itinéraire scientifique d’un prix Nobel* [André Lwoff, an Autobiography: Scientific Itinerary of a Nobel Laureate]. Edited by Laurent Loison. Paris: Hermann.

Lwoff, André, and Marguerite Lwoff. 1936. “Sur le rôle physiologique des codéhydrogénases pour Haemophilus parainfluenzae [On the Physiological Role of Codehydrogenases for Hemophilus parainfluenzae].” *Comptes rendus hebdomadaires des séances de l’Académie des sciences* [Weekly Reports of the Academy of Science] 203: 896–99.

———. 1937a. “La fonction de l’hémine, facteur de croissance pour Haemophilus influenzae [The Function of Hemin, Growth Factor for Hemophilus influenzae].” *Comptes rendus hebdomadaires des séances de l’Académie des sciences* [Weekly Reports of the Academy of Science] 204: 1510–12.

———. 1937b. “Rôle physiologique de l’hémine pour Haemophilus influenzae Pfeiffer [The Physiological Role of Hemin for Haemophilus influenzae Pfeiffer].” *Annales de l’Institut Pasteur* [Annals of the Pasteur Institute] 59(2): 129–36.

Lwoff, André, and Andries Querido. 1938. “Dosage de l’amide de l’acide nicotinique au moyen du test Proteus; principe de la méthode [Levels of the Amide of Nicotinic Acid Measured via the Proteus Test: Principles of the Method].” *Comptes rendus des séances de la Société de biologie et de ses filiales* [Reports of the Meetings of the Biology Society and Its Subsidiaries] 129: 1039–43.

Lwoff, Marguerite. 1928. “Action favorisante du sang sur la culture de Leptomonas ctenocephali Fanth. (Flagellé Trypanosomide) [The Favorable Effect of Blood on Cultures of Leptomonas

ctenocephali].” *Comptes rendus des séances de la Société de biologie et de ses filiales* [Reports of the Meetings of the Biology Society and Its Subsidiaries] 99: 472–74.

———. 1931. “La nature de la substance du sang indispensable aux trypanosomides [The Nature of the Substance in Blood Indispensable to Trypanosomides].” *Comptes rendus des séances de la Société de biologie et de ses filiales* [Reports of the Meetings of the Biology Society and Its Subsidiaries] 107: 1234–36.

Lyons, Maryinez. 1992. *The Colonial Disease: A Social History of Sleeping Sickness in Northern Zaire, 1900–1940.* Cambridge, UK: Cambridge University Press.

Mann, Thaddeus R. R. 1964. “David Keilin, 1887–1963.” *Biographical Memoirs of Fellows of the Royal Society* 10: 183–205. https://doi.org/10.1098/rsbm.1964.0011.

Mazumdar, Pauline M. H. 1995. *Species and Specificity: An Interpretation of the History of Immunology*. Cambridge, UK: Cambridge University Press.

Mendelsohn, J. Andrew. 2002. “‘Like All That Lives’: Biology, Medicine and Bacteria in the Age of Pasteur and Koch.” *History and Philosophy of the Life Sciences* 24(1): 3–36. https://www.jstor.org/stable/23332438.

Merck, Emanuel. 1889. *Merck’s Index of Fine Chemicals and Drugs for the Materia Medica and the Arts: Comprising a Summary of Whatever Chemical Products Are To-Day Adjudged as Being Useful in Either Medicine or Technology, with Average Values and Synonyms Affixed; a Guide for the Physician, Apothecary, Chemist, and Dealer*. New York: Cherouny. http://archive.org/details/mercksindexoffin00mercuoft.

———, ed. 1910. *Merck’s index*, Third Edition. Darnstadt: Eduard Roether. http://archive.org/details/mercksindex1910mercuoft.

Mesnil, Félix, and Alphonse Laveran. 1904. *Trypanosomes et trypanosomiases* [Trypanosomes and Trypanosomiases]. Paris: Masson. http://gallica.bnf.fr/ark:/12148/bpt6k55779749.

Méthot, Pierre-Olivier. 2019. “‘Birth, Life, and Death of Infectious Diseases’: Charles Nicolle (1866–1936) and the Invention of Medical Ecology in France.” *History and Philosophy of the Life Sciences* 41(2): 1–26. https://doi.org/10.1007/s40656-018-0238-6.

Meyerhof, Otto. 1924. *Chemical Dynamics of Life Phaenomena*. Philadelphia: J.B. Lippincott.

Myers, Natasha. 2015. *Rendering Life Molecular: Models, Modelers, and Excitable Matter*. Durham: Duke University Press.

Nachmansohn, David, Severo Ochoa, and Fritz A. Lipmann. 1952. “Otto Meyerhof: 1884–1951.” *Science* 115(2988): 365–68. https://doi.org/10.1126/science.115.2988.365.

Neill, Deborah. 2009. “Paul Ehrlich’s Colonial Connections: Scientific Networks and Sleeping Sickness Drug Therapy Research, 1900–1914.” *Social History of Medicine* 22(1): 61–77. https://doi.org/10.1093/shm/hkn094.

Nicolle, Charles. 1908. "Culture du parasite du bouton d'Orient [Culture of the Cutaneous Leishmaniasis Parasite]." *Comptes rendus hebdomadaires des séances de l'Académie des sciences* [Weekly Reports of the Academy of Science] 146: 842–43.

Novy, Frederick G., and Ward J. McNeal. 1904. "On the Cultivation of Trypanosoma Brucei." *The Journal of Infectious Diseases* 1(1): 1–30. https://www.jstor.org/stable/30071628.

Nye, Edwin R., and Mary E. Gibson. 1997. *Ronald Ross: Malariologist and Polymath: A Biography*. Basingstoke: Macmillan.

Osborne, Michael A. 2017. "Parasitology, Zoology, and Society in France, ca. 1880–1920." In *Biological Individuality: Integrating Scientific, Philosophical, and Historical Perspectives*, edited by Scott Lidgard and Lynn K. Nyhart, 206–24. Chicago: University of Chicago Press.

Pauly, Philip J. 1987. *Controlling Life: Jacques Loeb and the Engineering Ideal in Biology*. New York: Oxford University Press.

Pelis, Kim. 2006. *Charles Nicolle, Pasteur's Imperial Missionary: Typhus and Tunisia*. Rochester: University of Rochester Press.

Peters, Rudolph A. 1921. "The Substances Needed for the Growth of a Pure Culture of Colpidium Colpoda." *The Journal of Physiology* 55(1–2): 1–32. https://doi.org/10.1113/jphysiol.1921.sp001951.

RAC [Rockefeller Archive Center]. n.d. Rockefeller Foundation Records, Fellowships, RG 10.2, Subgroup 2: Fellowship recorder card; Discipline 9: Medical and Natural Sciences, FA426, Box 11, Lwoff (Dr.) André Michel (France).

———. 1932. Rockefeller Foundation Records, Officer Diaries, RG 12, M-R (FA393), Harry M. Miller, Diary - 1932, September 18.

———. 1939. Rockefeller Archive Center, Rockefeller Foundation Records, Officers' Diaries, RG 12, M-R (FA393), Harry M. Miller, Diary. January 9 – June 20, 1939, June 12.

Rader, Karen A. 2004. *Making Mice: Standardizing Animals for American Biomedical Research, 1900–1955*. Princeton: Princeton University Press.

Radin, Joanna. 2017. *Life on Ice: A History of New Uses for Cold Blood*. Chicago: University of Chicago Press. https://doi.org/10.7208/chicago/9780226448244.001.0001.

Rheinberger, Hans-Jörg. 1997. *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube.* Stanford: Stanford University Press.

Sankaran, Neeraja. 2021. *A Tale of Two Viruses: Parallels in the Research Trajectories of Tumor and Bacterial Viruses*. Pittsburgh: University of Pittsburgh Press.

Sapp, Jan. 1994. *Evolution by Association: A History of Symbiosis.* New York: Oxford University Press.

Sasges, Gerard. 2021. "Mold's Dominion: Science, Empire, and Capitalism in a Globalizing World." *The American Historical Review* 126(1): 82–108. https://doi.org/10.1093/ahr/rhab008.

Scheffler, Robin Wolfe. 2019. *A Contagious Cause: The American Hunt for Cancer Viruses and the Rise of Molecular Medicine*. Chicago: University of Chicago Press.

Schweiger, Hans-Georg. 1985. "Otto Meyerhof: 1884–1951." In *Semper Apertus: Sechshundert Jahre Ruprecht-Karls-Universität Heidelberg, 1386–1986* [Always Open: Six Centuries of the Ruprecht Karl University of Heidelberg, 1386-1986], edited by Wilhelm Doerr and Peter Anselm Riedl, 1457–73. Berlin: Springer.

Serres, Michel. 2007. *The Parasite.* Translated by Lawrence R Schehr. Minneapolis: University of Minnesota Press.

Simon, Jonathan. 2008. "Monitoring the Stable at the Pasteur Institute." *Science in Context* 21(2): 181–200. https://doi.org/10.1017/S0269889708001683.

Spies, Tom D., William B. Bean, and Robert E. Stone. 1938. "The Treatment of Subclinical and Classic Pellagra: Use of Nicotinic Acid, Nicotinic Acid Amide and Sodium Nicotinate, with Special Reference to the Vasodilator Action and the Effect on Mental Symptoms." *Journal of the American Medical Association* 111(7): 584–92. https://doi.org/10.1001/jama.1938.02790330004002.

Spies, Tom D., Clark Cooper, and M. A. Blankenhorn. 1938. "The Use of Nicotinic Acid in the Treatment of Pellagra." *Journal of the American Medical Association* 110(9): 622–27. https://doi.org/10.1001/jama.1938.02790090004002.

St. John-Brooks, Ralph T. 1922. "The National Collection of Type Cultures." Transactions of the British Mycological Society 7(4): 237–39. https://doi.org/10.1016/S0007-1536(22)80020-6.

St. John-Brooks, Ralph T., ed. 1937. *International Congress for Microbiology.* Report of Proceedings. London: Harrison.

Stoff, Heiko. 2012. *Wirkstoffe: eine Wissenschaftsgeschichte der Hormone, Vitamine und Enzyme, 1920–1970* [Active Substances: A Scientific History of Hormones, Vitamins, and Enzymes]. Stuttgart: Franz Steiner.

Strasser, Bruno J. 2003. "Who Cares about the Double Helix?" *Nature* 422(6934): 803–4. https://doi.org/10.1038/422803a.

———. 2006. "A World in One Dimension: Linus Pauling, Francis Crick and the Central Dogma of Molecular Biology." *History and Philosophy of the Life Sciences* 28(4): 491–512. https://www.jstor.org/stable/23334182.

———. 2019. *Collecting Experiments: Making Big Data Biology.* Chicago: University of Chicago Press.

Summers, William C. 1999. *Félix d'Herelle and the Origins of Molecular Biology*. New Haven, Conn.: Yale University Press.

Surita, Gina. 2022. *The 'Currency of the Cell': Energy Cycles and the Remaking of Metabolism, 1900–1970*. Ph.D. diss., Princeton University. https://dataspace.princeton.edu/handle/88435/dsp01fn107217z.

Sleeping Sickness Bureau. *1908*. "The Cultivation of Trypanosomes on Artificial Media." *Sleeping Sickness Bureau. Bulletin* 1(8–9): 287–94: 325–26.

Thjötta, Theodor. 1921. "Studies on Bacterial Nutrition: I. Growth of Bacillus Influenzæ in Hemoglobin-Free Media." *Journal of Experimental Medicine* 33(6): 763–71. https://doi.org/10.1084/jem.33.6.763.

Thjötta, Theodor, and Oswald T. Avery. 1921. "Studies on Bacterial Nutrition: II. Growth Accessory Substances in the Cultivation of Hemophilic Bacilli." *Journal of Experimental Medicine* 34(1): 97–114. https://doi.org/10.1084/jem.34.1.97.

Thomson, John Gordon, and John Alexander Sinton. 1912. "The Morphology of *Trypanosoma Gambiense* and *Trypanosoma Rhodesiense* in Cultures: And a Comparison with the Developmental Forms Described in *Glossina Palpalis*." *Annals of Tropical Medicine & Parasitology* 6(3): 331–56. https://doi.org/10.1080/00034983.1912.11687073.

Thudichum, Johann Ludwig Wilhelm. 1869. *On the Origin, Nature, and Uses of Liebig's Extract of Meat: With an Analytical Comparison of Other Essences and Preparations of Meat*. London: John Churchill. http://archive.org/details/b22278205.

Van Beneden, Pierre-Joseph. 1878. *Les commensaux et les parasites dans le règne animal* [Commensals and Parasites in the Animal Kingdom]. Paris: Baillière.

Velmet, Aro. 2020. *Pasteur's Empire: Bacteriology and Politics in France, Its Colonies, and the World*. New York: Oxford University Press.

Velmet, Aro, and Claas Kirchhelle. 2024. "Standards and Their Containers: Introduction to the Thematic Issue on Histories of Microbial Infrastructures." *Engaging Science, Technology, and Society* 10(1–2): 221–234. https://doi.org/10.17351/ests2023.1419.

Warburg, Otto, Walter Christian, and Alfred Griese. 1935. "Wasserstoffübertragendes Co-Ferment, seine Zusammensetzung und Wirkungsweise [Hydrogen-transferring Coferment, Its Composition, and Its Mode of Action]." *Biochemische Zeitschrift* 282: 157–205.

Wenyon, Charles M. 1914. "Kala-Azar in Malta, with Some Remarks on the Various Leishmaniases." *Transactions of The Royal Society of Tropical Medicine and Hygiene* 7(3): 97–111. https://doi.org/10.1016/S0035-9203(14)90001-3.

Wise, M. Norton. 2018. *Aesthetics, Industry, and Science: Hermann von Helmholtz and the Berlin Physical Society.* Chicago: University of Chicago Press.

Worboys, Michael. 1983. "The Emergence and Early Development of Parasitology." In *Parasitology: A Global Perspective*, edited by Kenneth S. Warren and John Z. Bowers, 1–18. New York: Springer-Verlag.

Yi, Doogab. 2008. "Cancer, Viruses, and Mass Migration: Paul Berg's Venture into Eukaryotic Biology and the Advent of Recombinant DNA Research and Technology, 1967–1980." *Journal of the History of Biology* 41(4): 589–636. https://doi.org/10.1007/s10739-008-9149-9.

Zotta, G. 1923. "A propos de l'action favorisante du sang sur le développement du Leptomonas pyrrhocoris dans le bouillon glucose [On the Favorable Effect of Blood on the Development of Leptomonas pyrrhocoris in Glucose Broth]." *Comptes rendus hebdomadaires des séances de l'Académie des sciences* [Weekly Reports of the Academy of Science] 88: 913–15.