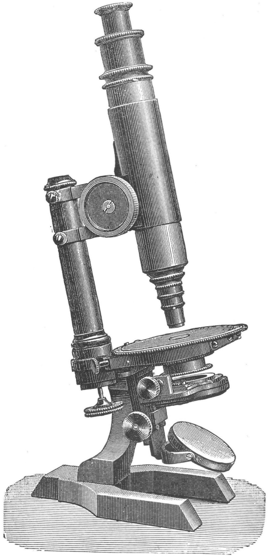
Microbiology in the 19th Century

Fermentation, spontaneous generation,

and the germ theory of disease

Waseda University, SILS,
History of Modern Earth and Life Sciences

Microscopes



A Seibert microscope

Microscopes were used in the 17th century to great effect by scholars like Robert Hooke and Antonie van Leeuwenhoek, who both published extensively about their discoveries – often accompanied by beautiful illustrations.

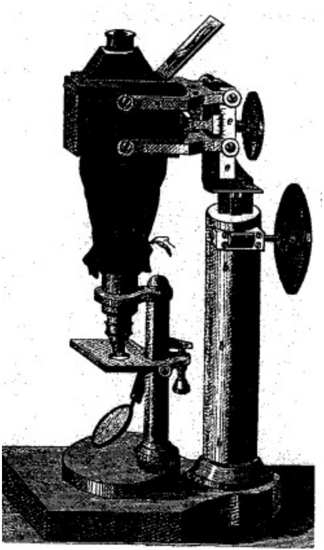
Throughout the 18th century, microscopes were one of the instruments regularly produced by an ever expanding scientific instrument industry. Most of these were made for well-to-do amateurs and natural historians.

When Pasteur and Koch began their work, they were readily able to buy instruments made by specialists, such as this Seibert microscope.

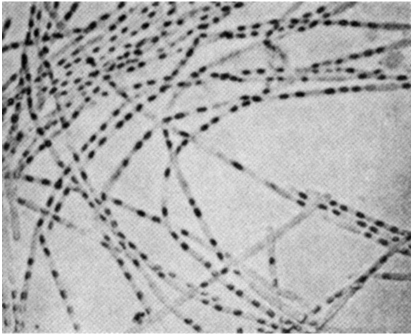
Photomicroscopy

A major desideratum of both the new cell theory and microbiology was the production of accurate images – reflecting what was seen in the microscope – to accompany publication. In general, practitioners produced their own drawings, but some, such as Koch, pioneered photographic techniques.

For these purposes, pre-made instruments – such as this one on the right – were insufficient and custom equipment had to be built. At this time, photography was still done with individually prepared plates, and for photomicroscopy the light source was redirected sunlight.

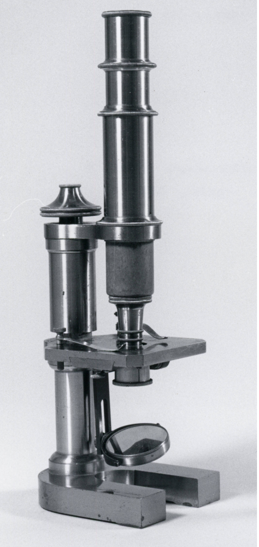


Photomicroscopic apparatus



Two of the first photographs of bacteria, by Robert Koch

Zeiss microscopes



A Zeiss microscope

At the greater magnifications necessary to see smaller bacteria, traditional bifocal microscopes did not have enough resolving power to produce clear images. The major breakthroughs in this regard were made by the physicist Ernst Abbe (1840–1905), who studied the optics of the lenses and the system of illumination.

Abbe realized that microscopes could be made by suspending the lens in oil and collecting more of the diffracting light rays. As a consultant, and eventually owner, of the Carl Zeiss Microscope Company, Abbe helped design the first commercially available oil-immersion microscopes – which were used by Robert Koch.

Early investigations of microorganisms, *Chaos*

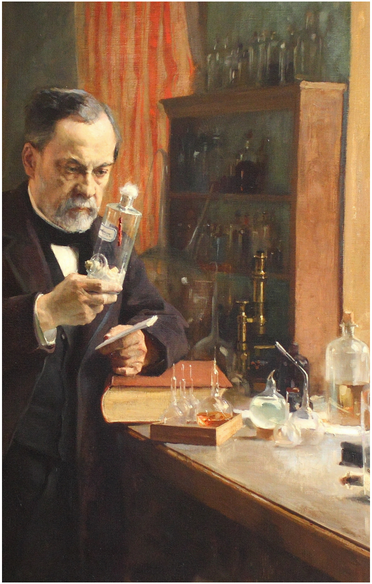
Microorganisms had been seen under single lens microscopes in the 17th century by Leeuwenhoek, Joblot, and others, but there was no consensus about whether they were animals or plants. Linnaeus could not discern any differences in the various microorganisms and placed them all in a category called *Vermes* in the class *Chaos*.

Ernst Haeckel (1834–1919) separated the bacteria from other microorganisms and called them *Protists*. Ferdinand Cohn (1828–1898) classified the bacteria as a type of animal – as opposed to plant – and through *morphological classification* came to the conclusion that there were different species of bacteria.

Microorganisms in the 19th and 20th centuries

These were, essentially, *molds*, *yeasts*, *bacteria*, and *protozoa*. *Viruses* were recognized, practically, later in the 19th century and *archaea* were distinguished from bacteria only in the 1960s.

Louis Pasteur (1822–1895)



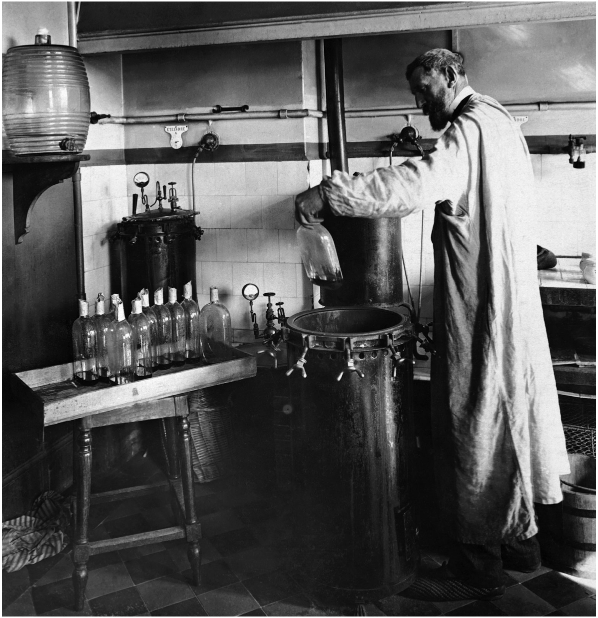
- From a middle class family.
- Took a degree in chemistry from Dijon and eventually entered the École Normale Supérieure.
- Became director of scientific studies at the École Normale, and then professor at École Nationale Supérieure des Beaux-Arts.
- Founding director of the Institut Pasteur.
- By the time he died, he was one of the most famous scientists in the world and a national hero in France.

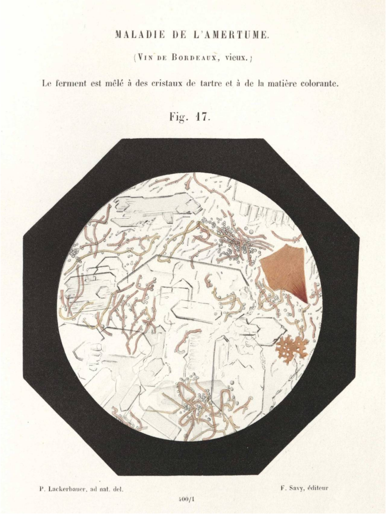
Fermentation studies

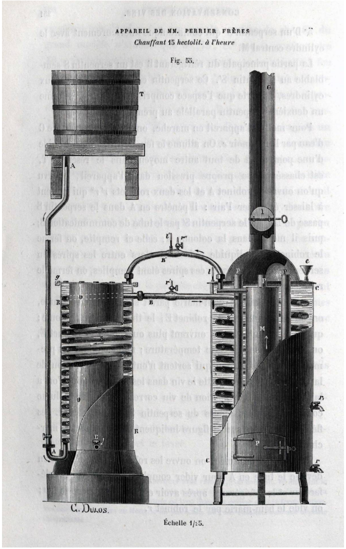
While teaching in Lille in 1856, Pasteur began to study the process of fermentation. In a series of studies, he established that fermentation is not a form of decomposition, but is the result of living organisms – which he called a *ferment*. He showed that during the usual process of brewing beer or making wine, a certain yeast turns sugar into alcohol and carbonic acid, while if another type of yeast is introduced, the product is lactic acid, which turns the drink sour. He also showed that the rate of fermentation varied with the quantity of air, or rather oxigen.

This work led to the conclusion that beer, wine and milk could be spoiled by certain microorganisms, and the development of various industrial processes – still called pasteurization in English – for destroying pernicious bacteria and molds in beverages.

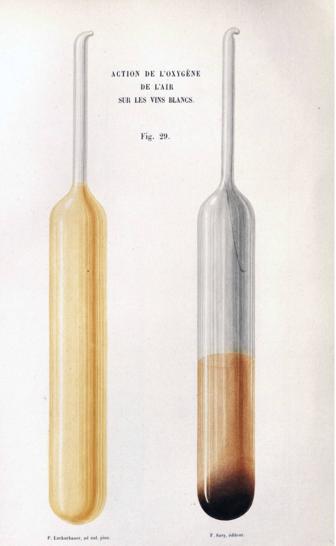
Pasteur at work in the laboratory

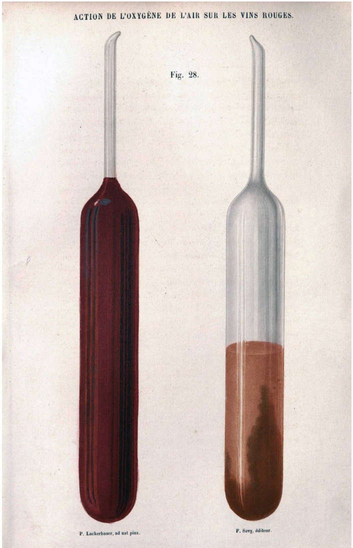






Pasteur, *Études sur le vin* (1873)





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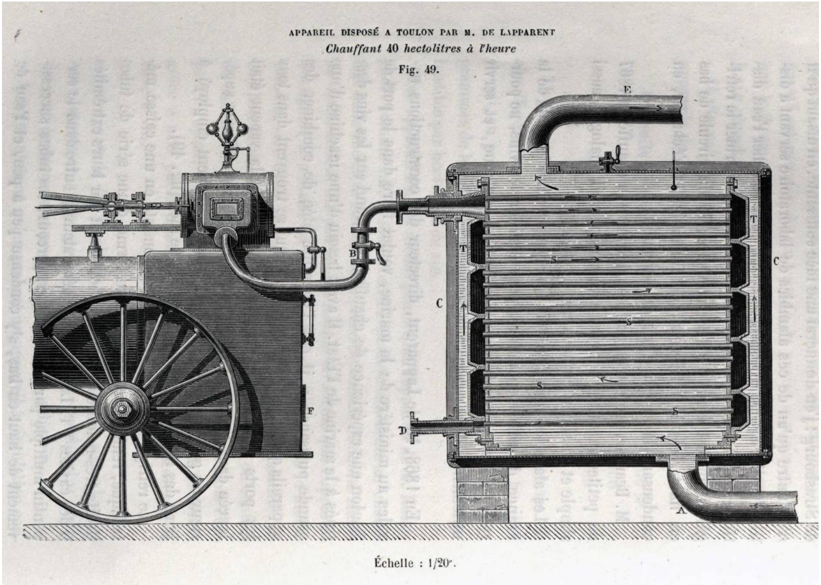
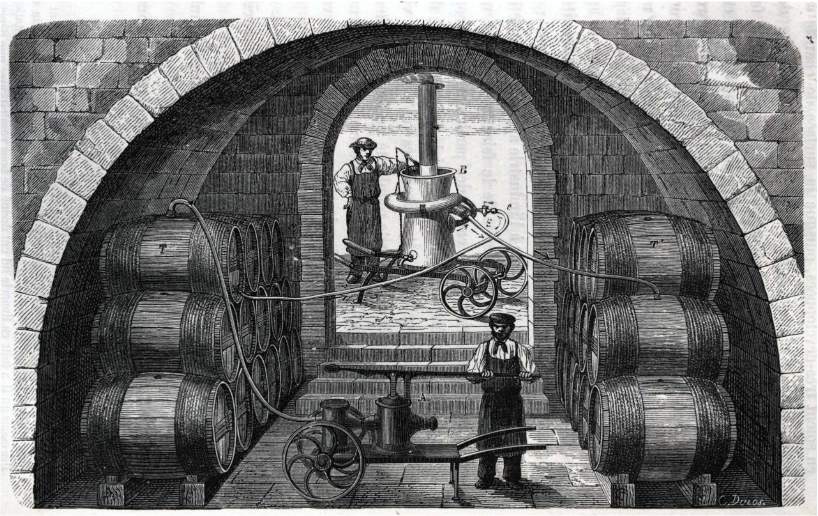


Pasteur, *Études sur le vin* (1873)



Pasteur, *Études sur le vin* (1873)

Spontaneous generation

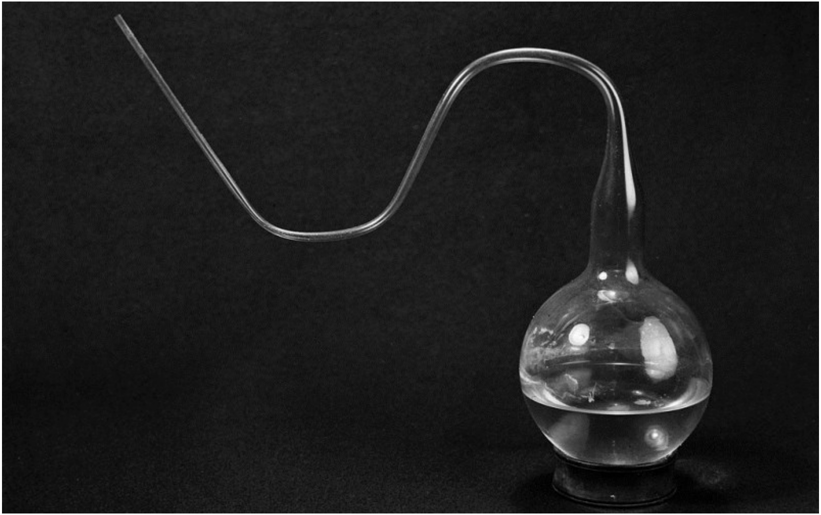
Belief in spontaneous generation was the position that life – microorganisms, worms, or insects – could form naturally from *inert matter*. It was a position that had been held since antiquity by various people, but in the 18th century it became the favored explanation for the growth of microorganisms. Although there were a number of debates about, and experiments probing, the nature and possibility of spontaneous generation, none of them were definitively conclusive.

The prevailing opinion began to turn against spontaneous generation through the course of the 19th century – first under the influence of German *Naturphilosophie*, and then with the emergence of the cell theory. In this environment, a number of new experiments were carried out which seemed to show that when a nutrient media was heated and put under pressure and the air filtered, all growth could be prevented.

The Pasteur-Pouchet debate

In 1859, Félix-Archimède Pouchet (1800–1872), who was a Lamarkian and a catastrophist, argued that *eggs*, not mature organisms, can arise spontaneously. He claimed to have observed such growth in many of the established experiments.

In 1861, Pasteur submitted an essay arguing against spontaneous generation. He pointed out that air drawn through a cotton plug contained thousands of different microorganisms and argued that these were contaminating Pouchet's experiments. He designed a swan-necked flask for producing a sterile environment, which did not produce growth. There was long debate between Pasteur and Pouchet concerning the nature and possibility of spontaneous generation in which each man asserted that the other's experiments were failures. Although it was not possible to decide the issue definitively in this manner, the consensus came to be that Pasteur was correct.



One of Pasteur’s swan-necked flasks

The experimenter's regress

It was not possible for either side in the debate to convince the other. Pasteur claimed that Pouchet was not able to create sufficiently sterile air and that his flasks were always contaminated, while Pouchet claimed that Pasteur was destroying the "vegetative force" by boiling too hard, or removing the "vital component" from the air by using extreme means to purify it.

They both moved to using clean, untreated air, or room temperature filtrations. Pastuer showed that flasks exposed at higher altitudes in the French Alps produced little or no mold; Pouchet challenged this with a series of experiments in the Pyrenees. Nevertheless, Pastuer never accepted the results of Pouchet's experiments – simply defining all air that gave rise to microorganisms as being contaminated. The French Académie des Sciences established a commission that was stacked with Pasteur's supporters, Pouchet withdrew but did not conceed.

Lister and antiseptic surgery

Following Pasteur's work on fermentation and his arguments against spontaneous generation, Joseph Lister (1827–1912), a Scottish physician, promoted various techniques to reduce infection in surgeries. At this time, the importance of cleanliness in surgical procedures was not fully understood, and some 40% of major surgeries resulted in death by infection.

Lister's innovation was to use an antiseptic agent to clean the surgeon's hands, the instruments, the patient's wounds, as well as spraying the air. The most common agent was a *phenol spray*, which smells like coal tar and leaves an oily coating. Through these procedures, he was able to greatly reduce the rates of infection.

It was later shown by Koch that phenol is not a true disinfectant, and Lister and his colleagues switched to more effective chemicals.

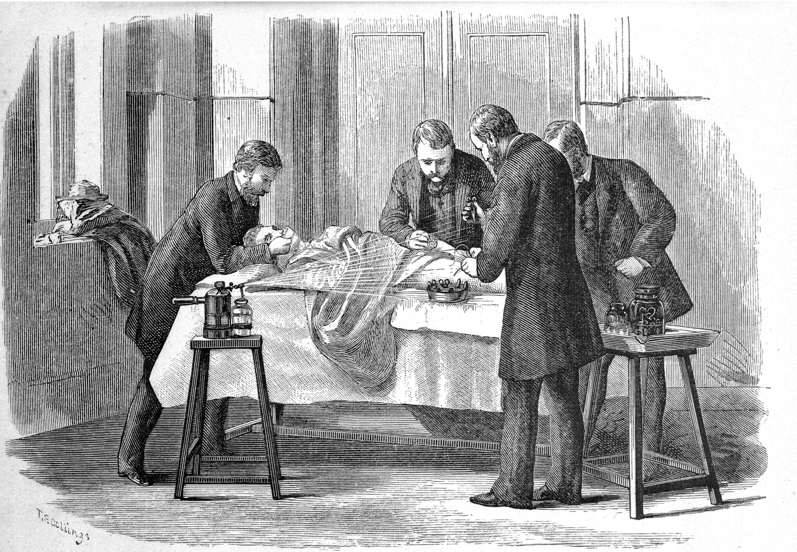


FIG. 23.

This figure represents the general arrangement of surgeon, assistants, towels, spray, &c., in an operation performed with complete aseptic precautions. The distance of the spray from the wound, the arrangement of the wet towels, the position of the trough containing the instruments, the position of the small dish with the lotion, the position of the house surgeon and dresser, so that the former always has his hands in the cloud of the spray, and the latter hands the instruments into the spray and various other points, are shown.

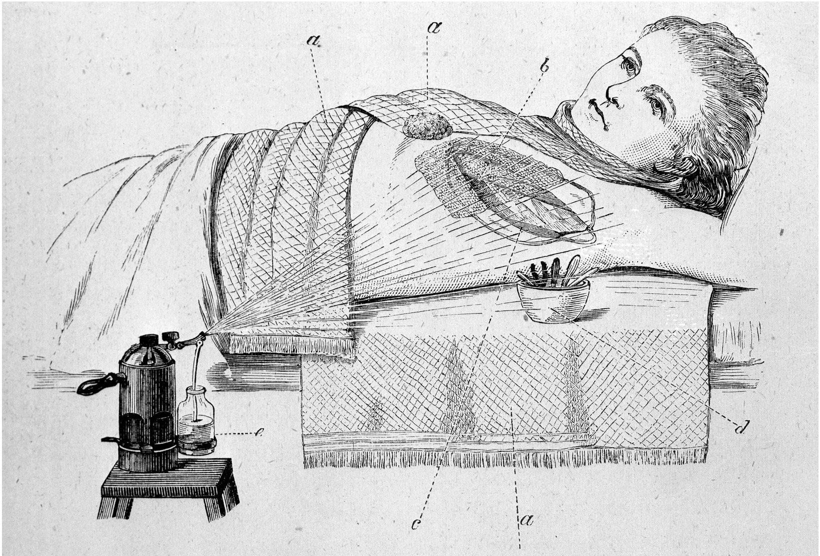
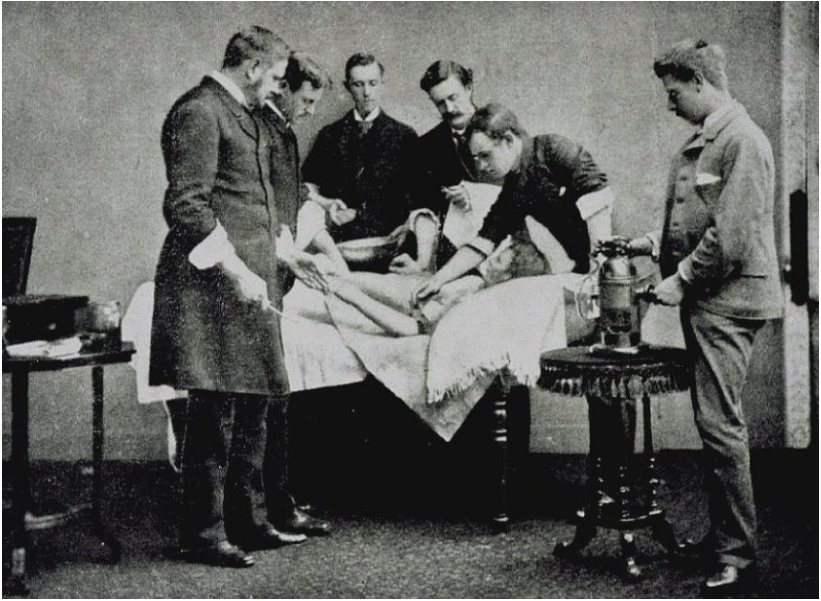


FIG. 24.—TO SHOW THE ARRANGEMENT OF TOWELS, ETC., IN A LARGE OPERATION.

Lister's carbolic acid (phenol) spray apparatus

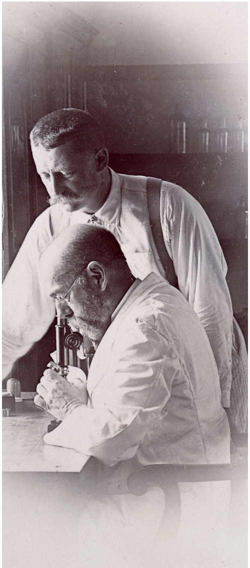


Photograph of a surgery at Aberdeen, Scotland, 1883

A surgery by Dr. J.C. Warren, using ether, Boston General Hospital, 1847

Robert Koch (1843–1910)

- Born into a middle class family and worked as a provincial doctor.
- After a number of major discoveries, he moved to Berlin and worked at the Imperial Department of Health.
- Worked as professor and director at the University of Berlin.
- Spent many years in Africa and South East Asia, working on tropical diseases.
- He set the germ theory of disease and bacteriology on firm foundations.
- He became an international celebrity by identifying the agents of some of the world's most deadly diseases.



Koch and Pfeiffer

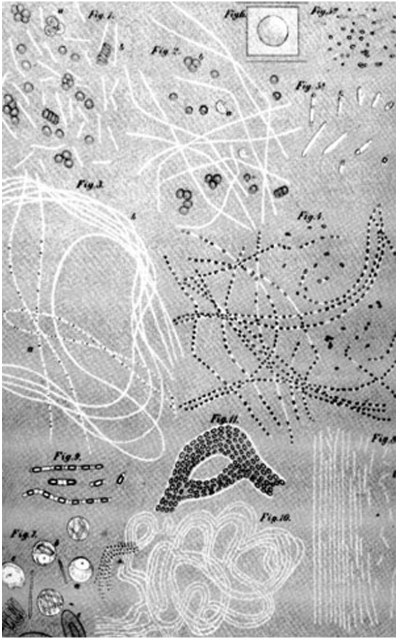
The identification *Bacillus anthracis*

Koch's first experimental achievement was made after he had established himself as a physician in Wollstein. He began by a series of microscopic studies of the blood of sheep that had died of anthrax, which was an infectious disease affecting livestock.

He followed the full life cycle of the bacteria, which lead to the discovery of endospores – a heat-resistant spore that was dormant, but viable, for a long period of time. This explained how livestock could contract the disease apparently from the field itself. He cultured *Bacillus anthracis* and showed that it could be used to induce the disease in healthy animals.

In 1876, he took all of his experimental apparatus to the University of Breslau and showed his experiments to Ferdinand Cohn (1828–1898) and Julius Cohnheim (1839–1884), who were immediately impressed with Koch's results.

Koch's drawing of *Bacillus anthracis*



Pasteur's anthrax vaccine

Pasteur had managed to immunize chickens against chicken cholera, by weakening the virulence of the organism through cultivation in a liquid culture, and in the 1870s, turned these methods to anthrax. He isolated *Bacillus anthracis* and cultivated it through many transfers of a liquid culture, so as to weaken it. Once he had a weakened strain of the organism, he staged a major demonstration of his preventative preparation.

In 1881, at Pouilly-le-Fort he performed a public experiment on 24 sheep, a goat and some cows. He first injected one group of animals with the weakened strain of *Bacillus anthracis*, while he kept another group uninoculated. After 15 days, he reinjected all of the animals with a virulent sample of the bacteria. The animals that had been inoculated survived, while those in the control group died or became ill.

Pasteur called this weakened form of the organism, a vaccine.

The germ theory of disease

The germ theory of disease – the proposition that each infectious disease was caused by one specific type of microorganism – was assumed by various scholars in the 19th century, but was set on a solid foundation by Koch.

A technical requirement necessary to test the theory was the production of *pure cultures*. Koch addressed this by the development of plate technique on a solid medium.

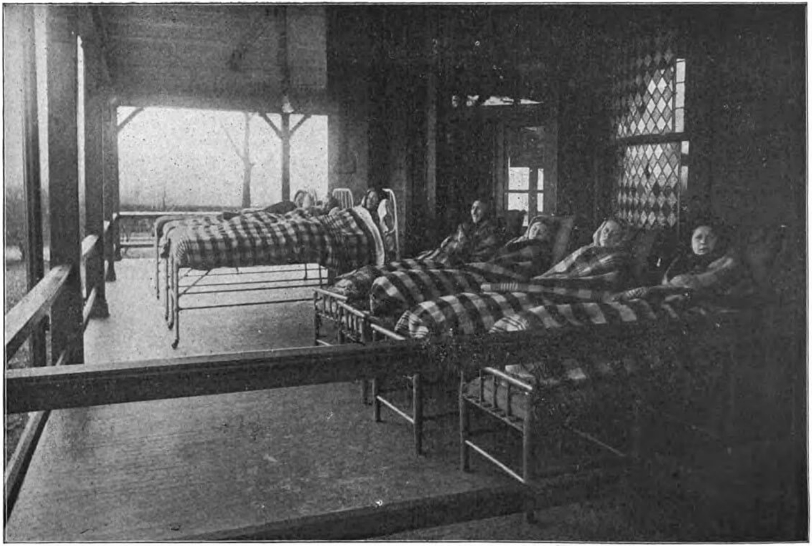
He and his colleagues also established what became known as Koch's postulates:

1) The organism must be found in the diseased tissue.
2) The organism must be isolated and grown in *pure culture*.
3) The pure culture must be shown to induce the disease experimentally.
4) The organism must be re-isolated from the inoculated, diseased experimental host.

Tuberculosis (consumption)

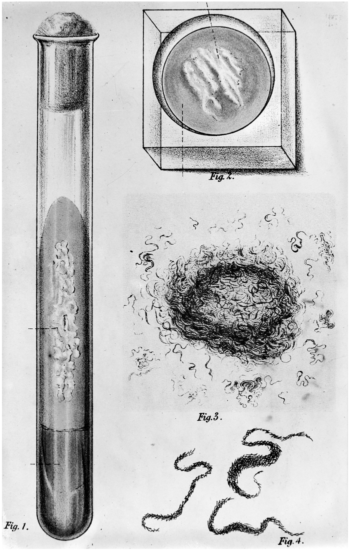
Tuberculosis is a chronic infectious disease that generally effects the lungs. The symptoms are a chronic cough, coughing up blood, low fevers, night sweats and weight loss – hence the term “consumption.” It hasd been known since ancient times, and the only treatment used to be rest, usually in a dry climate. Tuberculosis used to be one of the great killers, and as many as 30% of middle-age mortalities were due to it.

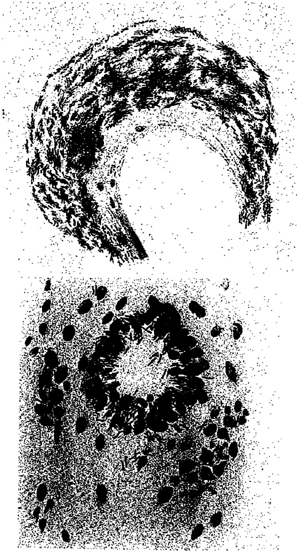
The discovery that propelled Koch to international fame was that of *Mycobacterium tuberculosis*. He isolated a characteristic bacteria in affected tissues, cultured it on coagulated blood serum at 37–38°, and used this pure culture to infect guinea pigs – in this way, following through the full program to demonstrate the etiology of the disease.



TAKING THE CURE.

A tuberculosis sanatorium in Pittsburgh, Pennsylvania, 1907





Koch could not photograph *Mycobacterium tuberculosis*, so he made drawings

Cholera

Cholera is another infectious disease, that comes in epidemics and used to be a great killer. The symptoms are diarrhea, vomiting, muscle cramps, sunken eyes, cold skin and wrinkling due to dehydration. It is highly contagious and used to be lethal. In the early 19th century, there was a growing consensus that it was caused by contaminated drinking water.

Although the small *Vibrio cholerae* that causes the disease was first seen and described by Filippo Pacini (1812–1883), there was still disagreement about the causes of the disease when Koch took up the problem. He was sent by the German government as part of an official expedition to Egypt and India to try to identify the microorganism responsible. Koch identified and cultured the *Vibrio cholerae*, but because no animal can be infected with cholera, he had to turn to epidemiological methods to argue his point.

Koch on the German cholera expedition to Egypt, 1884

The bubonic plague, or “Black Death”

The bubonic plague is an infectious disease spread by fleas and rodents, which became periodically epidemic starting from the medieval period due to the opening of trade routes, increases of urban poor, and urban overcrowding. The symptoms begin with fever, headaches and vomiting, followed by painful and swollen lymph nodes, which darken to a blackish color and may break open and ooze pus.

The plague is highly infectious and, the rates of death for those infected were very high. There are considered to have been three great pandemics of the plague: in the 6th and 7th centuries, killing perhaps *half* of the inhabitants of Europe; starting in the 14th century and recurring periodically, killing some 200 to 250 million people; and twice in the 19th century, killing some 10s of millions of people. It is hard to be sure of these numbers, but the earlier epidemics are thought to have killed some 30%–50% percent of the affected populations.

The plague in Hong Kong, 1894

In 1894, the plague resurfaced from southwest China, Yunnan Province, and moved into Canton and then Hong Kong. From Hong Kong, the disease was spread to various port towns around the world. This final outbreak was controlled by state implementation of various practices of *modern hygienics*.

The outbreak in Hong Kong was focused in Tai Ping Shan, which was a crowed Chinese district with no running water, no sewage system and no proper drainage. The colonial authorities imposed a strict regime involving the disinfection of houses, the forcible removal of residents, and the razing of buildings. They also invited a famous bacteriologist of the Koch school, Shibasaburo Kitasato (北里 柴三郎, 1853–1931), to come and study the disease.

Hong Kong, Tai Ping Shan, 1894

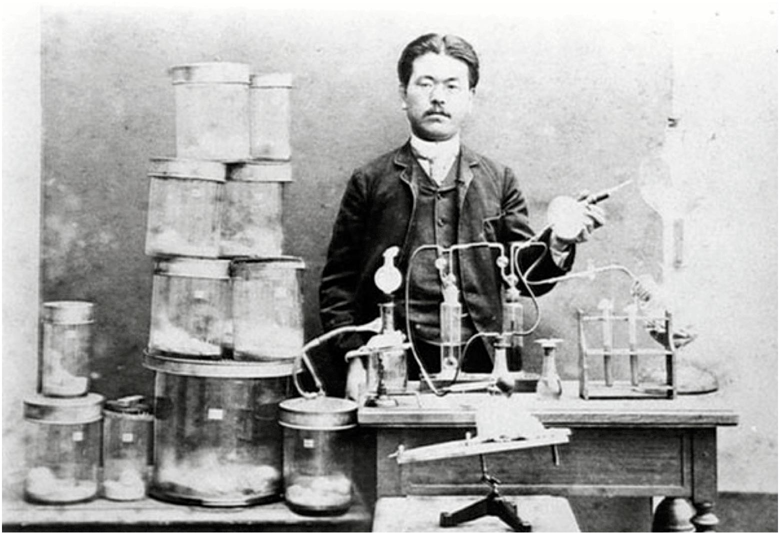
Colonial authorities disinfecting Tai Ping Shan, 1894

Hong Kong, a plague ravaged street, 1894

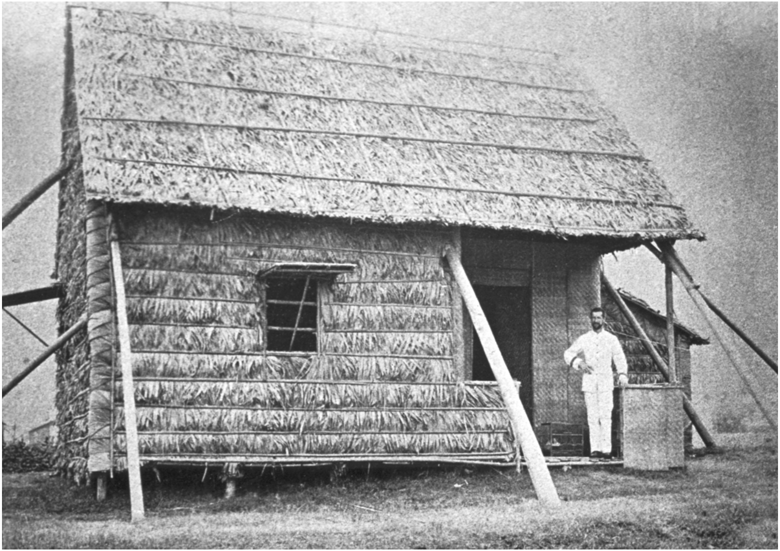
The Japanese and French expeditions

Kitasato was a student of Koch, trained in Berlin and then working in Tokyo. He was sent by the Japanese government, at the request of the British, and was invited to work in a well equipped laboratory. A few days later, Alexandre Yersin (1863–1943) arrived as a representative of the French colonial government. Yersin had been trained at the Pasteur Institute, and hence belonged to a different school of bacteriology.

The two men did not cooperate, and while Kitasato had the help of the colonial authorities and a fully equipped lab, Yersin worked on his own in a temporary hut using bodies he had stolen from the morgue. Although Kitasato published his results first, his description of the microoranism was vague and it is sometimes claimed that he described the bacteria responsible for pneumonia. Yersin published his own account somewhat later, and the bacteria was eventually named after Yersin: *Yersinia pestis*.



Kitasato in the Berlin lab where he discovered the tetanus antitoxin



Yersin in front of the hut where he discovered the agent of the bubonic plague

Experimental animals

Pasteur and Koch pioneered the use of animals as living laboratories. One of the fundamental principles of their approach was the use of animals as a test of an isolated microorganism in order to see if the animal would present the sought disease symptoms. If the animal presented, it was killed and autopsied. These practices lead to the inoculation and subsequent killing of experimental animals on a level that might shock us and for which it would be difficult to find funding under current ethics rules.

On the other hand, we have to bear in mind the extent to which infectious diseases ravaged human society, and the fact that most people were used to witnessing the slaughter of animals on the farm and at the butcher. Unlike the situation with vivisection, in the 19th century there was almost no objecting to the use of experimental animals in the investigations of infectious diseases.

Overview

- We looked at important developments in microcopy in the 19th century.
- We have discussed the birth of bacteriology and the demise of the theory of spontaneous generation.
- We looked at the rise of antiseptic surgery.
- We looked at the work of Pasteur and Koch in developing the model of the germ theory of disease and structuring the paradigm of this new approach.
- As an example, we discussed the isolation of the microbe responsible for the bubonic plague – one of the most deadly diseases in history.