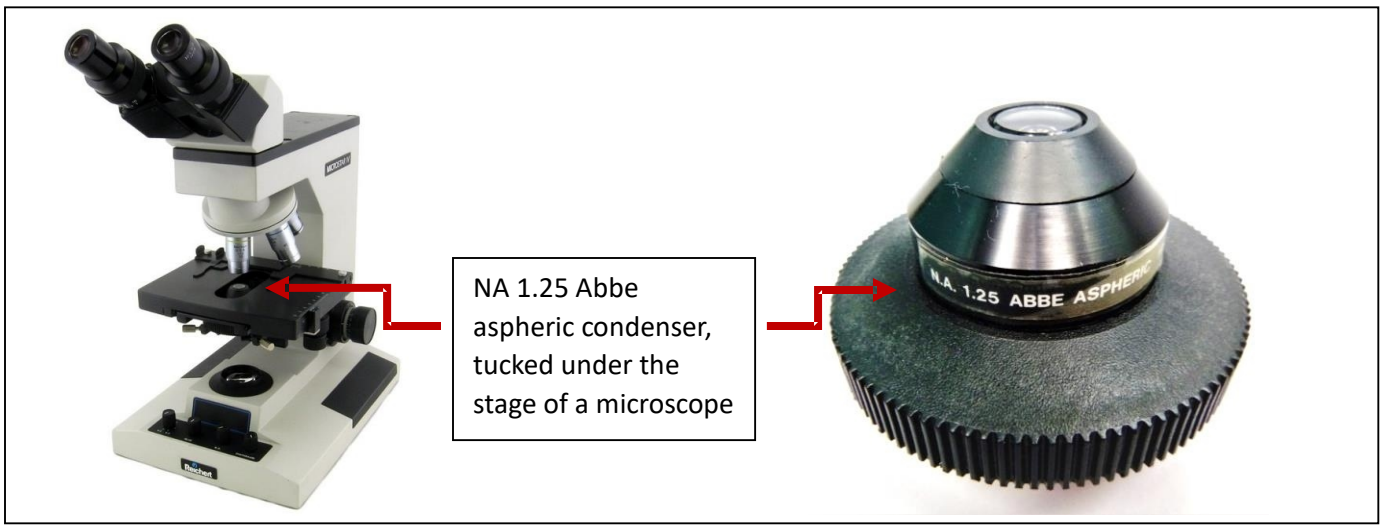
Ernst Abbe, hero of microscopes, science and humanity

Ernst Abbe is a hero from an important time in history. I first learned his name because of the Abbe condenser that perfectly focuses light on the specimen in my microscope. Abbe was not a medical doctor, but he was a thoroughly scientific man who also became part of a social movement that went on to save more lives than anything ever invented by doctors.

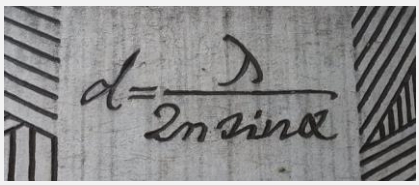


Abbe at Zeiss, contributing to a medical revolution

Late 19th century Germany saw the beginnings of our modern scientific age. German doctors, chemists, and opticians were the best in the world. Carl Zeiss opened an optics workshop in Jena, Germany in 1846 that over the next few decades used cutting edge science to develop vastly improved microscopes. Grinding lenses started out as an art done by skilled craftsman, but eventually physicists developed equations that could produce theoretically perfect lenses. Doctors began to use microscopes and germ theory was developed by Robert Koch in Germany and Louis Pasteur in France, looking at disease causing bacteria with microscopes.

Ernst Abbe was born into a poor household in central Germany in 1840, during the industrial revolution. His dad worked in a textile factory, 14 to 16 hour long days on his feet, tending a spinning machine he could not leave. He peed in a pail and ate sandwiches that Ernst brought to him. Abbe never forgot his father's suffering. Terrible conditions in factories prompted Marx and Engels to write *The Communist Manifesto* in 1849 decrying the exploitation of workers like Ernst's father. Although the family was very poor, they recognized that Ernst was smart and so they sent him to school, in part with financial help from his father's employer. Ernst continued on to the Universities of Jena and Göttingen, learning higher math. Eventually Abbe became a professor of physics, mechanics and mathematics. Carl Zeiss needed a mathematician and hired Abbe in 1866. Abbe did much more than crunch numbers. He was a master of optics research, discovering numerical aperture (NA): a broader cone of light allows

better resolution. Abbe found the limit of how fine a detail a microscope can see (the Abbe formula, d= λ /2NA), designed apochromatic lenses (free of false color fringes) and later the first oil immersion lenses (extra high magnification). He invented the "Abbe refractometer" that quantifies how fast light moves through different clear substances. He proved the necessity of a good microscope condenser and perfected it, inventing the "Abbe condenser" in 1870 which still bears his name. Most microscopes still use variations of Abbe condensers 150 years later. Thanks to Abbe, and also Otto Schott (who scientifically perfected the chemistry of optical glass), Carl Zeiss was making the best microscopes in the world by the end of the 19 th century, showing details as small as we can see with standard light microscopes today. Abbe published many dozens of scientific papers advancing the science of optics. Carl Zeiss recognized the brilliance of Ernst Abbe's work and made him a partner in the business. The son of a poor factory worker eventually became a millionaire factory owner.



Monument at Jena University to Abbe's microscope resolution limit formula
(his handwriting was bad enough to be a doctor's)

$d = \lambda/(2n \bullet \sin(\alpha))$ defines the resolution of a microscope objective lens

where d = distance of the closest lines that can be seen as separate (aka resolution, R)

λ = wavelength of light used (blue light can see smaller details than red light)

n = refractive index of the glass in the lens (this is why flourite lenses can be better)

α = half angle of the cone of light (produced by the condenser) entering the objective

Abbe defined **Numerical Aperture = n • sin(α)** so Resolution (same as d) can also be stated as **$R = \lambda$ /2 NA**

In the last half of the 19th century, improved microscopes helped the preeminent Prussian (German) Doctor Rudolph Virchow become the first Pathologist, showing all our cells come from other cells, how cancers and blood clots spread, and how to do an autopsy to determine the cause of death scientifically. Virchow also founded the field of Public Health. He found bad health usually comes from harsh living conditions, and he called typhoid and tuberculosis "social diseases" because they more often killed the poor than the rich. He advocated for education, improved diet, better sanitation, and democracy to reduce poverty. No one is perfect and Virchow didn't accept Darwin's theory of evolution or Koch's germ theory. He thought bacteria moved into tissues only after death. Zeiss microscopes helped Dr. Robert Koch discover and prove many awful, commonly fatal diseases, including anthrax, tuberculosis and cholera, were caused by contagious microscopic bacterial organisms, overthrowing the "miasma" theory that contagion was caused by bad smells. For over 2300 years doctors since Hippocrates had been wrong about what caused most human deaths, until Koch's 1880's microscopic observations and animal experiments finally proved the germ theory of disease.

Humans got sicker, then healthier

But the biggest gains in human health in all of history emerged less from Koch's great medical revolution and more from a social revolution emerging at the same time and place. Health and wealth have always been intertwined. In the past almost everyone was poor and many people around the world still are. Let us summarize *Homo sapiens'* health history. In 1651 philosopher Thomas Hobbes assumed earliest man's life was "solitary, poor, nasty, brutish and short" writing at a time when many Britons lived such lives. A relatively few stone age skeletons seem to agree. But my anthropology professors thought ancient **hunters and gatherers** were protected from epidemic disease by living in dispersed 50 to 100 person wandering groups, finished gathering food by noon, and owned only what they could carry (little to fight over), leading to comfortable 70 year lives, all spent with family and friends they knew. It is possible human life was good for over 250,00 years, but we do not have enough evidence to know for sure. Human lives seem to have lessened soon after we domesticated grains and settled in towns. Multiple skeletons from Europe and the US show people got shorter (less healthy) and life expectancy dropped to about 40 years around the time of the **agricultural revolution**. With production of surplus food, it was the first time some could be rich and others poor. For the next 10,000 years most humans were poor rural peasant farmers (tens of thousands for every king) with short hard lives. By 5000 years ago steep social hierarchies enabled building the great pyramids of ancient Egyptian civilization. The Roman Empire came 3000 years later. The Middle Ages brought pandemics of plague ('black death"), cholera, wars and famines, all killing many people by age 30. Most people blamed illness on supernatural causes, but physicians believed in four humors (magical fluids) and miasmas. Average life expectancy at birth in Europe over the last 1000 years was about 30-35 years, even though a lucky few people, often rich or notable, lived to old age. Women often died in childbirth and more than 1 in 3 of their many babies died of malnutrition, pneumonia or diarrhea before they were 5 years old. Old English custom was to not even name children at birth. Big new ideas- the Renaissance, the Reformation and early **Scientific Revolution** emerged in Europe from about 1400 to 1700. Spanish and Portuguese sailors discovered the world was very much bigger than Europe. The Moors came to Spain with Arabic translations of Greek classics and their own early scientific advances. Martin Luther translated the Bible into German, a language people still spoke. Copernicus proposed the Earth circles around the Sun. Free thinking was in the air, but it didn't yet translate into health improvements. Most people still died of infectious diseases, including rampant tuberculosis (still a common human infection, it killed 1.6 million in 2021). Most humans remained harshly treated serf farmers who lived unhealthy, mostly short lives.

Starting about 300 years ago, British coal fired up the **industrial revolution**. Steam and oil powered machines created consumer goods and great wealth, but at first all that wealth went

to the owners of the machines. Working to death in a factory was not initially an improvement over working to death in the fields. Even in the US, life expectancy was still around 40 in 1900 but grew throughout the 20th century, rising quickly to 68 years by 1950. That dramatic, 28 year gain in life expectancy in just half a century was unprecedented and nothing like it has happened since. Most of that lengthening of lives was due to labor reforms, which spread out of late 19th century Germany along with germ theory and public health ideas. Germs were discovered in the late 1800s, but antibiotics were not widely used until the 1940s. Before labor reforms, many half-starved factory workers lived cramped together, 10 in a dark, stale room, with 40 people sharing a bathroom that spilled human waste onto the sidewalk. By 1900 2.3 million New Yorkers lived in tenements. No wonder many died young of infections such as cholera and tuberculosis. Raising desperately poor workers to a level of being only moderately poor resulted in the biggest gains in health that humanity has ever seen. **Social and labor reforms** led to life saving improvements in housing, food and sanitation for the masses of poor people. Most US medical schools did not adopt modern scientific views until after the 1910 Flexner report and from about 1950 on modern treatments (antibiotics, new vaccines, and later heart and cancer drugs) slowly raised US life expectancy by 9 more years to 77 years in 2000. Notice the timing. The biggest known health gains in all of human history happened at a time when we had figured out disease on a basic scientific level, but before the invention of effective medical treatments. Larger gains came from rich people (reluctantly) sharing a little bit of their wealth with the workers. Labor organizers fought hard for change, culminating in worldwide early 20th century labor reforms. For the first time, many workers began to earn a decent wage, enough to pay for a reasonable life. The industrial revolution had created a vast excess of material goods, but average human health languished until a basic level of material comfort began to spread to all social classes. Sharing (often forced) saved the world.

Social reform, not medicines, created the biggest health miracle in all of history. This surprising truth is revealed by a rational look at the facts, rather than being swayed by the fairy tales doctors tell about themselves. I first learned sewers saved more lives than doctors in the one history lecture taught by a historian at Johns Hopkins Medical School in the 1980's. The 20 other history lectures were by medical professors and celebrated pioneering surgeons who saved women from breast cancer and rescued babies born blue with their heart plumbing backwards, and praised researchers who discovered DNA, invented cancer drugs and mapped brain receptors finding targets for anti-depressants. Modern medical science is truly amazing and inspiring. So amazing in fact that I forgot my medical school's one real history lesson for the next 2 decades. Eventually I had to rediscover for myself that the biggest drivers of human health are still social. My patients are likely to live longer if they are rich and sick than if they are poor and healthy. As average living conditions improve so does human health. Since the invention of farming most humans lived in rural poverty and died young. Today in the "third

world" health is still sometimes determined by absolute poverty. Although conditions are improving, almost a billion people still cling to life on less than 2 dollars a day, risking fatal infections related to lack of food, clean water or shelter. (In the developed world today, even people living in severe *relative* poverty mostly have enough food and shelter to sustain a meager life, yet still suffer poor health because of social discrimination). Overall people are healthier, and in 2008 50% of humans lived in towns and cities for the first time. As more populations developed economically, *global* average life expectancy has grown from about 32 years in 1900 to about 73 years today. During my lifetime the average human moved to the city, escaped from extreme poverty and can now expect to live a longer life than Americans did in the 1950s. Since the industrial revolution, a fast growing human population has unfortunately ruined much of the surface of our planet. But when people gain control over their own lives, and especially when women become educated, families have fewer (and healthier) children. The pace of human population growth is slowing, and more people than ever want to make the world a better place. The biggest truths can be amazing and can also inspire optimism. Human groups all have the same biologic potential, so the different health outcomes of different social groups are subject to change, if we commit to it again.

Our hero Ernst Abbe not only designed the world's best microscopes, he personally committed by putting his money where his mouth was, and became a labor reformer.

far left

1879 microscope by Carl Zeiss with optics by Abbe

left

1968 German stamp

images, Wikipedia

Ernst Abbey, social reformer

Ernst grew up poor but became a self-made millionaire. The Zeiss microscopes he perfected to mathematical precision were so sought after that the factory kept doubling in size and employees every few years. Zeiss and Abbe treated their workers very well by the changing standards of the day, and talked about giving the company to the workers when they died. In 1888 Zeiss passed away first, and Abbe bought out Carl's son, becoming sole owner. Abbe established the Carl Zeiss Foundation in 1889 and 2 years later divested ownership, making the Foundation the owner of the company. In 1896 Abbe explained why he treated workers well:

"I can base my conviction, like few others, on my own experience… I became over time myself an entrepreneur and capitalist and had to make decisions accordingly. At the same time, however, I had to see my position through the eyes of a worker's son who could not grow any entrepreneur or capitalist eyes. I could contemplate my position from both sides."

Through the Foundation, the workers inherited the business when Abbe died in 1905. The Carl Zeiss Foundation laid out a bold new litany of 10 workers' rights. Abbe treated his workers better than many workers are treated today, over 130 years later. Notice how many of these then new worker's rights you enjoy today, and thank Ernst Abbe and other 19 th century labor reformers:

- an 8 hour work day ("8 hours to work, 8 hours to sleep, and 8 hours to be a human being")

- a living wage, plus a profit sharing payment each Christmas

- a paid annual vacation and holidays

- retirement at age 65 with a guaranteed pension

- job security

- 75% of usual wage as sick pay, plus guaranteed payment for medicines and treatment

- elected workers' representatives consult with management about worker's interests

- workplace library, theatre, sports center and spa (sounds like working for Google but in 1889)

- sponsorship of education, child care, cultural institutions and universities

- no boss can earn more the 10 times the average worker

Abbe was a brilliant scientist who became a millionaire then gave away his fortune to the workers. What an amazing and modern Saint Ernst Abbe was. (Ernst might have just rolled over in his grave. He didn't do it for God, as Abbe was a self avowed atheist.)

Giving of oneself and one's money for the benefit of others is hard. Or at least I suffer from a streak of selfishness in my soul that makes it hard. But I have learned, from the examples of my youngest daughter and Ernst Abbe among others, how important and rewarding selfless giving can be. I'm no Ernst Abbe. But I am lucky to be the son of a factory worker, able to go to university, get a science oriented job and earn more money than my ancestors could dream of. I think living on two different socioeconomic levels during my life has helped me be able to finally see the big outlines of human wellbeing in much the same ways as Abbe did. I don't have a company to give to the workers. But I hope to live the remainder of my life a little more down to earth than my pay would allow. I plan to keep riding my bike to work (as Abbe did) and to proclaim a science based, optimistic view of humanity. Both modern medicine and social democracy largely emerged from scientific and social revolutions aided by Abbe. More people willingly sharing a little wealth today might save us from future violent revolutions.

If you want to read more about Abbe there are many on-line sources. Abbe wrote numerous scientific articles and some books, all in German. No English language biography of Abbe is published as a book. A brief good biography with references is at:

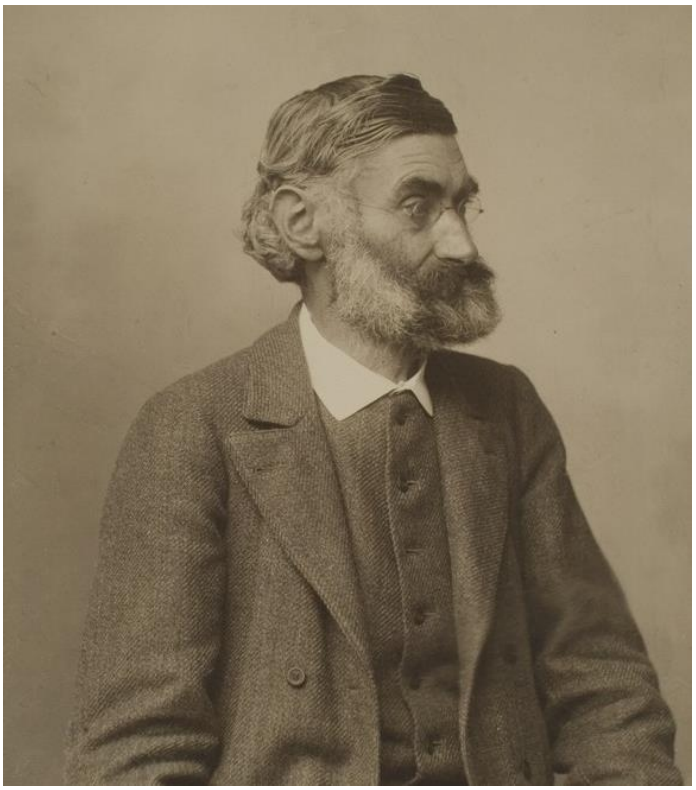
https://mathshistory.st-andrews.ac.uk/Biographies/Abbe/

Abbe's quote and Zeiss Foundation principles are from the excellent January 2019 Micscape (microscopy-uk.org) article by retired Zeiss worker and microscope enthusiast, Fritz Schulze:

"We all do not belong to ourselves". Ernst Abbe 1840-1905: a social reformer

Ernst Abbe in 1877
age 37, Director of Zeiss optical lab
photo from Wikipedia

Original, University of Heidelberg Library



Essay by
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March 2023
Minnesota, USA

Extra, for microscope enthusiasts

Ernst Abbe was a brilliant optical engineer. He was mathematician, physicist and engineer all at once. The work he did 150 years ago is college physics today. Among other achievements he was the first to prove the theoretical resolution limit of the light microscope, then he built microscopes to that limit. Microscopes can't clearly magnify past about 1000X because of the wave nature of light. He used test slides inscribed with fine parallel lines and examined the interference patterns at the back focal plane of the microscope objective. He realized that constructive and destructive interference is what allowed sharp focus on edges. Fine resolution disappeared when he took away the 2nd and 3rd order interference patterns by reducing the aperture. He did the math for multiple levels of interference and reached his resolution formula $R = \lambda/2\ NA$ (where NA is numerical aperture, equalling the refractive index of the glass in the lens multiplied by sine of the half angle of the illuminating cone of light). Numerical aperture was a construct of Abbe's, a simple number so important it is still inscribed on all your microscope objectives and condensers today. Working with various advanced optical glasses invented by Otto Schott, Abbe went on to design and build the first apochromatic objectives (perfect color correction, which remains very expensive today) and the first homogenous immersion objectives. Abbe enabled the first sharp look at bacteria.

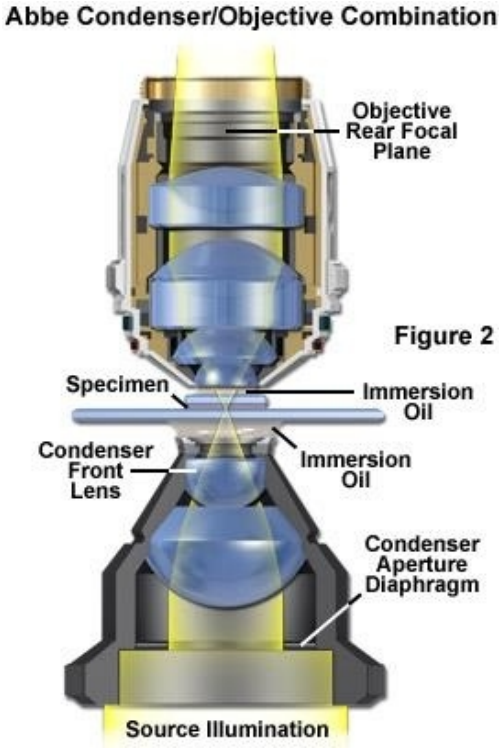

Figure 2

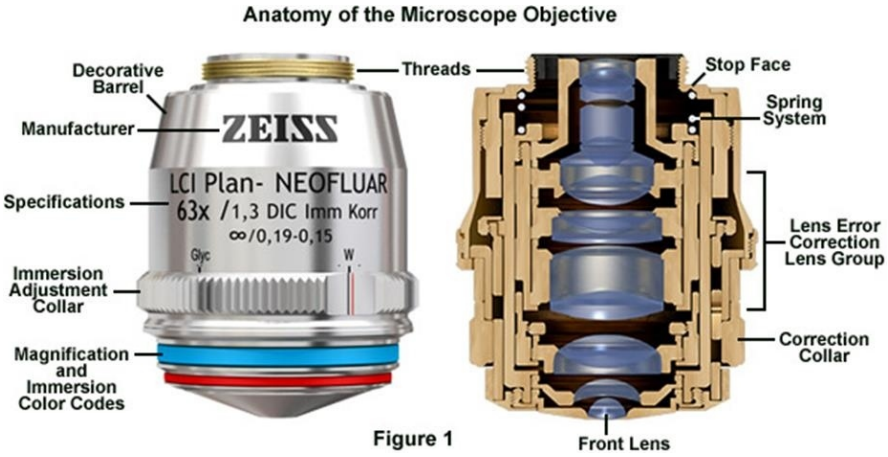

Figure 1

Modern Abbe condenser and microscope objective from Abbe's company at zeiss-campus.magnet.fsu.edu

One of Abbe's eponymous inventions, the condenser, came in 1870, after just 4 years at Zeiss. His 2 lens design (left, bottom) is simple and close to perfect, so many modern condensers use some variation of it. Most mid level microscopes have a basic Abbe condenser. Some modern variants are aspheric and/or achromatic.

Ed Ward, comments welcomed, email – eward1897 AT gmail DOT com.

Published in the March 2023 issue of *Micscape* magazine.

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