The Scanning Electron Microscope (SEM)

One route to a STEM career (Science, Technology, Engineering, Math)
An optical microscope you may have used

An electron microscope
Magnified Images

• Magnification
  – What does 100 X or 100 times mean?
  – The image is 100 times larger than the object
    • The object is the [very small] thing you are looking at!
    • The image on a monitor and is big enough to see.
Magnified Images

• But what is meant by an “image”?

• Magnification is the factor by which the image is larger than the actual object.
Microscopy is important for a number of reasons
All Modern Electronics Is Based on Integrated Circuits

Details of those circuits can only be seen with a microscope. (The entire device is half the size of a penny.)
Microscopes Can Allow Us to See Diseased Cells

An example of one kind of cancer cell
We Can See Fatigued, Fractured Metals

Fractured aluminum
Ranges of Magnifications

• Optical microscopes: 1 – 2000X
  – Cells can be seen but details cannot be resolved

• Scanning electron microscopes: 15 – 1,000,000X
  – Can image carbon nanotubes but not atoms

• Transmission electron microscopes: up to 50,000,000X
  – Can image atomic structure of surfaces!

• The SEM covers a huge fraction of the range of possible magnifications.
Optical Magnification

Magnification depends on distance from object to lens: The closer the object is to the focal point, the higher the magnification.
Electron source (typically heated filament)

Electrons accelerated to high energy

Lenses focus beam onto object

Electromagnetic coils scan beam across object.

Step (pixel) size: few atoms to ¼ size of pixels on monitor

The SEM scans a very fine beam (as small as the bond length of atoms in a silicon crystal) across the object at the same time the signal from the detector illuminates a pixel on the monitor.
SEM Magnification

• Magnification of SEM is simply scan length on monitor (screen width) divided by scan length on sample or object.

• To increase magnification, simply scan a smaller area on the sample, but blow the image up to the same size on the monitor!
Fly eye
Examples of Stuff You Can Visualize with an SEM
CeO$_2$-coated boron nano-particles
Scott Anderson Group U of U Chemistry Dept.

Four times the energy density of conventional fuels like gasoline
Virus
Hannah Wampler
Marc Porter Group
U of U Chemistry Dept.
Can You Guess What Common Materials Look Like Under the Electron Microscope?
Pollen
Hair with mascara!
Mozzarella Cheese
How Do You Think Electron Microscopes Make the World a Better Place?
Cancer Detection
Failure Analysis

Fractured aluminum
Integrated circuit at 2 kV
Shows surface structure

Integrated circuit at 30 kV
Shows sub-surface structure
Take Advantage of Large Depth of Field

Utah Neural Array

Optical Microscope

SEM
The Utah Arm
(Controlled by the Utah Neural Array)
Forensics

SEM image of gunshot residue

X-ray spectrum giving quantitative chemical analysis of above particle
Process Control for Water Purification
Via Nanomaterials
Silver nanocubes used to detect low concentrations of pathogens (chemical warfare agents)
• Scanning electron microscopes are used by scientists and engineers in a wide variety of settings

• SEM operators
  – have interesting jobs (they get to look at a lot of cool stuff!)
  – Make the world a better place
  – Make a good living
SEM Technician: $22.92/hr
SEM technician’s supervisor (engineer): $33.50 – 49.50/hr
Which of the Following People Do You Think Are SEM Operators?
Optically Generated Lithographic Pattern

Objective is to extend existing technology to 3-D biological substrates

Precious Cantu
Currently on Fulbright to Oxford
Dr. Krista Carlson, Mistress of the U of U Metallurgy Department’s Hitachi SEM, whose extreme love of water (via her snowboard) led her to found SolaPur, with markets among backpackers and in India.
Dr. Jesus Paolo Perez
Master of $6M of analytical equipment with FEI Quanta SEM in the U of U Surface Analysis Laboratory
String cheese: basically mozzarella with protein molecules aligned parallel to each other.

Dr. Almut Vollmer
Postdoc at USU
Can be used to focus light to regions smaller than possible with conventional optics, lowering detection limits in medical diagnostics.
Joseph Ziebarth, graduate of SLCC Nanotechnology Certificate Program Operating His SEM at IM Flash in Lehi
• How do you think these people got where they are?
  – The really fun, high paying jobs require a college degree (4 years)...some of them even a PhD (another 4-6 years).
  – Jobs are also available to those with Associate Degrees (2 years) or only some college.
  – Some STEM technical jobs require only a high school diploma.
  – **ALL** STEM jobs require proficiency in math and at least one field of science.
Microscopy is an important tool and vocation in modern society.

Essential in many fields
- Science
- Engineering
- Forensics
- Foods and agriculture
- Medical

Careers in science and technology allow you to help society while making a good living.

For access to these fields you must start now to focus on and do well in your math and science classes.