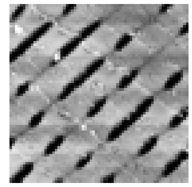
Size and Scale

Compact disc nano-technology



Teaching Notes

Overview

In this lesson, students will explore the difference between two related concepts—size and scale—as they examine images of the surface of a compact disc. Size is the physical magnitude, extent, or bulk of something; scale is the relationship between the size of an object and the way that size is represented numerically or visually.

To explore these concepts, students will use a public-domain image processing and analysis program developed at the National Institutes of Health called *ImageJ*. *ImageJ* is a Java-based program and is cross-platform. The program may be downloaded from the *ImageJ* website at http://rsb.info.nih.gov/ij/. Before performing this lesson with your students, you may want to acquaint them with the basic features and tools of *ImageJ*. Look at the documentation file at http:rsb.info.nih.gov/ij/docs/index.html for instructions to operate *Image J*. Tips and instructions are also given on the lesson worksheet in the right hand column under the icon. This same icon in the lesson instructions and discussion indicates there is an *Image J* activity.

Images used in this lesson can be downloaded from http://invsee.eas.asu.edu/Modules/size&scale/CDimages.html, as well as opened from the IN-VSEE CD-ROM. If you would like a free copy of the IN-VSEE CD-ROM, please email IN-VSEE at invsee@asu.edu.

This lesson is subdivided into three sections. Each section is designed to take about 50 minutes to complete. You may customize the presentation of this lesson by performing all or only parts of it. Each section has a lesson worksheet and a data sheet that can be accessed on-line or printed from a PDF file.

Section I: **What is size and what is scale?**

In *ImageJ*, students open an image of a CD disc and a quarter. The students measure a quarter in class. This measurement is used to determine and set the scale for measurement and analyisis in *Image J*. The inner and outer diameters of the data storage region on the CD image are measured and the data storage area calculated. Students investigate the concepts of precision and accuracy by making multiple measurements both with and without magnification of the image.

Section II: **How do compact discs store information?**

Students observe the microscopic features of a CD using a series of scanning probe microscope images. They measure the sizes of pits and bumps on the disc, which store data on a CD. Measurements are used to determine the length of one “bit” of information.

Section III: **How much data can you store on a disc?**

Students use their calculations from Section II to relate the dimensions of the features of the CD to the amount of information that may be stored on a disc. They also speculate about the relationship between the size of the features and the dimensions of the laser beam needed to read information from the disc.

Goal

Students will explore the concepts of size and scale as they measure microscopic features of an optical disc to discover how digital data is stored.

Topics

- Size and scale
- Optical disc storage media
- Scanning Probe Micros-copy

National Science Education Standards

- Structure and properties of matter
- Understandings about science and technology
- Science and technology in local, national and global challenges
- Science as a human endeavor
- Nature of scientific knowledge

Time requirement

- Three 50-minute class periods

Materials needed

- Any CD disk
- Quarter
- Metric ruler

Objectives

Students will:

- Measure the size of macroscopic and microscopic features of a CD-ROM disc and relate size to scale.
- Measurements recorded to appropriate significant figures.
- Differentiate between precision and accuracy of measurement.
- Measure and calculate bit length, bit area, track pitch and roughness to discover how digital data is stored on an optical disc.
- Relate bit area and track pitch to laser spot size.

Prerequisites

Prior to this lesson, students should

- Know and be able to use SI units for measuring length.

SI units are introduced in the Size and Scale module at http://invsee.eas.asu.edu/Modules/size&scale/Unit2/Unit2.htm.

Acknowledgments

Lesson developed in collaboration by the IN-VSEE Project, Arizona State University, Tempe, Arizona, and the Center for Image Processing in Education, Tucson, Arizona.

Answers

Section I

1. Answers will vary somewhat. An estimate of the diameter of a CD is about 3.5 to 4 quarters.
2. Answers will vary somewhat. The diameter of a quarter is approximately 23.5 mm in diameter.
3. There are three numerical places (significant figures) in the measurement of the diameter of the quarter.
4. The measurement is accurate to 23 millimeters.
5. The area of the quarter is 434 mm^2 using a diameter of 23.5 mm.

Table 1

Measurement trial	Diameter of inner band (D1)	Diameter of outer band (D2)	Area (A) of data storage	Average area value
No magnification				
#1	33.0 mm	105 mm	7,800 mm^2	7760 mm^2
#2	32.4 mm	103 mm	7,500 mm^2	
#3	33.0 mm	106 mm	7,970 mm^2	
With magnification				
#1	33.0 mm	102 mm	7,310 mm^2	7440 mm^2
#2	32.4 mm	103 mm	7,500 mm^2	
#3	32.4 mm	103 mm	7,500 mm^2	

6. The diameter of the CD (D_2) is shown in Table 1 below.
7. The area of the CD is 8,659 mm^2.

8-10. Answers will vary depending upon how students make their measurements.

Representative answers are shown in Table 1. Student answers should be more precise with magnification.

11. Representative answers are shown in Table 1.
12. Answers will vary depending upon measurements. Given the values in the table above, the % error is 11.3.
13. Representative answers are shown in Table 1.
14. Answers will vary depending upon measurements. Given the values in the table above, the % error is 15.0.
15. Answers will vary. The new measurements should be more precise because with magnification it is easier to measure the diameter at the same place every time.
16. Answers will vary. The new measurements may not be more accurate because of the gradation shown for the edge of a pit or bump.
17. The scale on the hair and red blood cell images is in micrometers. The scale on the nickel atoms image is in angstroms ***(make sure is correct?!)***.
18. The hair is 125 µm in diameter, the red blood cell is 5.6 µm in diameter and the nickel atoms are ***??get images!!!*** angstroms in diameter.
19. The scale of the CD-ROM is in centimeters which is 1/100 of a meter. The scale on the hair and red blood cell images is in micrometers which is 1/10,000 of a centimeter. The scale on the nickel atoms image is in angstroms which is 10,000 times smaller than a micrometer.

Section II

Table 2

Image	Area (μm^2)	# per quarter	# per CD
CD I	2,500	174	3,464
CD II	400	1,085	21,648
CD III	100	4,340	86,590
CD IV	25	17,360	346,360
CD V	1	434,000	8,659,000

1. Student answers will vary. There are series of dark, oblong spots arranged in linear rows against a gray background.
2. The dark spots are low points.
3. The area measurement is shown in Table 2 below.
4. A representative answer is shown in the Table 2 above.

Table 3: Measurements of bit

	CD I	CD II	CD III	CD IV	CD V
1	1.14	1.03	1.14	1.25	-
2	0.98	1.22	1.24	-	-
3	1.08	1.29	1.17	-	-
4	1.25	1.21	1.28	-	-
5	1.14	1.10	-	-	-
6	1.25	1.24	-	-	-
7	1.14	1.21	-	-	-
8	1.14	1.21	-	-	-
9	1.08	1.10	-	-	-
10	1.08	1.03	-	-	-
Average	1.13	1.16	1.25	1.25	-

5. No, the lengths of the pits and space between them vary.
6. Representative measurements and an average are shown in Table 3 below.
7. A representative measurement is shown in Table 2.
8. Representative calculations are shown in Table 2.
9. Answers will vary. Representative measurements and average are shown in Table 3.
10. No, because the magnification on the CDV image is so high that the length of one bit doesn't fit within the image.

Section III

1. Answers will vary depending upon the measurement of the track pitch. Using a track pitch value of 1.7 µm, approximately 52 tracks would fit on a hair of 90 µm in diameter.
2. Answers will vary depending upon measurement of bit length and track pitch. Using a value of 1.2 µm for bit length and 1.7 µm for track pitch, the area covered by a bit of information is approximately 2.0 µm.
3. Answers will vary. There are approximately 54 bits in a 100 μm^2 box on this image. Thus, the area of a bit is calculated to be 1.9 μm^2.
4. Answers will vary. Using the measurements and calculations above, the bit density is 0.54 bits/μm^2.
5. Total area available to hold data on a CD is 8,750,000 μm^2.
6. Answers will vary. Using the measurements and calculations above, 4,725,000 bits of information can be stored on a CD.
7. Answers will vary. Using the measurements and calculations above, there are 590,625 bytes/CD.
8. The bumps are all the same height.
9. The spaces between the peaks are not flat but have some small bumps.
10. Answers will vary depending upon where the plot profile is drawn. The bumps in the spaces range between 5-15 nm.
11. The area of the hypothetical bit is 8 Å^2.
12. Answers will vary. Using the calculations above, 1.1 x 10^{10} bytes of information could fit on a CD stamped with this stamper.
13. Answers will vary. ***(I don't have a copy of this animation that works so I'm not sure about a representative answer).***
14. Answers will vary somewhat. A representative mean pixel value is 223.9.
15. Answers will vary somewhat. A representative standard deviation is 4.88.
16. The standard deviation is much smaller than the mean pixel value.
17. Answers will vary somewhat. A representative mean pixel value is 55.63.
18. Answers will vary somewhat. A representative standard deviation is 50.05.
19. In this case, the standard deviation is only somewhat smaller.
20. The diameter of the laser spot should be at least 1 µm in diameter.

Size and Scale

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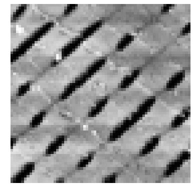


Lesson

In this lesson, you will explore the concepts of size and scale by examining features on the surface of a compact disc (CD). A CD is one type of optical storage media. Optical storage technology uses optical scanning techniques to store and read massive amounts of information in a compact area. Optical media encode data by altering reflectivity, transmission, or other optical characteristics of the material. Other examples of optical media include CD-ROMs that store software and digital video discs (DVDs).

Size is the physical magnitude, extent, or bulk of something. For our purposes we will mostly consider size to be length, although we will also talk a bit about surface area and volume.

Scale is the relationship between the actual length you are measuring and the way that length is represented numerically or visually. A scale has a succession of ascending and descending steps, or relative dimensions, used to assess the absolute or relative size of some property of an object, such as length, temperature, or mass.

I. What is size and what is scale?

The **size** of a CD can be easily measured in centimeters, but the data storage features on the CD are on a much smaller **scale**, about one-millionth of a meter. Using image processing software and images obtained with various microscopes, you will measure the size of several features of a CD to discover how information is stored and read on an optical disk.

Setting a scale

Open the image **cdrom.gif**. This digital image of a CD and a quarter was taken with a standard digital camera.

File/Open.../cdrom.gif

1. Estimate how many quarters equal the diameter of the CD. Enter your answers on the data sheet.

Before you can measure the size of the CD with the image analysis software, *Image J*, you must set the scale, or calibrate, the digital image. You set the scale for the image by telling the computer how much distance is represented by one **pixel** of the image. To do this, you must know the size of an object in the image in an appropriate unit of measurement. In this exercise, you will use the diameter of a quarter to calibrate your image.

Pixel is an abbreviation for "**pict**ure **el**ement," the smallest discrete element that when combined together form an image on a computer monitor or a television screen

Locate a quarter from the change in someone's pocket and use a metric ruler to measure the **diameter** of the quarter in millimeters (mm). Estimate the diameter of the quarter to a tenth of a mm.

The **diameter** is the longest line across the face of the quarter.

2. What is the diameter of the quarter in mm?
3. How many numerical places (digits) are in your measurement? (This is the number of **significant figures** that any calculation you perform with this measurement can contain.)
4. To which numerical place is your measurement accurate?
5. What is the **area** of the quarter in square millimeters (mm^2)?

Learn more about **significant figures** in the Size and Scale module at http://invsee.eas.asu.edu/Modules/size&scale/Unit2/Unit2.htm

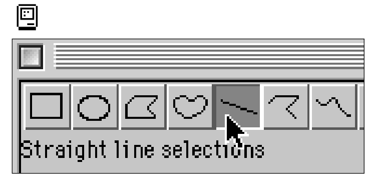
Area of a circle $= \pi r^2$

Radius (r) $= \frac{1}{2}$ **diameter (d)**

$\pi \approx$ **3.14**

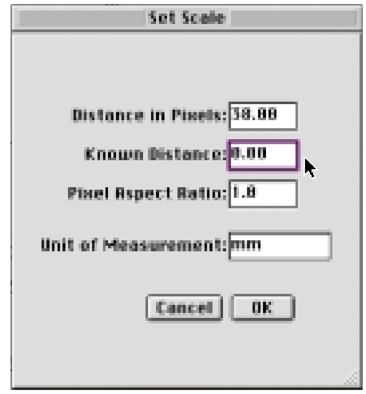
To calibrate the image using your measurement of the quarter, use the following steps:

Highlight the straight line selection tool and drag a line across the diameter of the quarter. Make sure you select the true diameter of the quarter, through the center point.



- Choose **Analyze/Set Scale...** to set the scale for the image using your measurement of the quarter. In the dialog box, change the **Unit of Measurement** to mm and enter the **Known Distance** (the diameter of the quarter). Click **OK**.
- Choose **Analyze/Measure** to check your scale. The measurement shown in the *ImageJ* window should be the same as the **Known Distance** you entered for your scale.

Analyze/Set Scale...



Measuring size

Once you have scaled the image in millimeters, you may now measure the size (diameter, in this case) of the CD.

- Highlight the straight line selection tool and select the diameter of the CD.
- Choose **Analyze/Measure** to measure the diameter of the CD. The results show in the *ImageJ* window.

Analyze/Measure

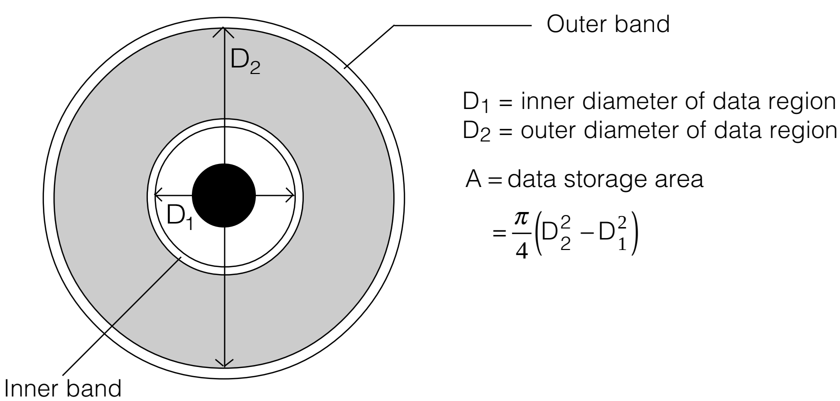
6. What is the diameter of a CD (D_2 as shown below) in mm? (How many significant figures can your measurement have?) Record this measurement in Table 1 on your **Data Sheet** in the "no magnification, #1" section.
7. What is the area of the CD in mm^2? Record this in Table 1.

Area of a circle = πr^2

Radius (r) = $\frac{1}{2}$ diameter (d)

$\pi \approx$ **3.14**

On the surface of a CD there are two shiny bands: one near the center plastic portion of the CD, the other near the outer edge. These are called the inner and outer bands. These bands represent the boundaries of the data storing region of the CD. No data can be stored inside the inner band or outside the outer band. Look at an actual CD to better identify these regions.



- Highlight the straight line selection tool and select the diameter of the inner clear plastic portion of the CD (D_1).
- Measure the clear plastic portion of the CD (D_1).

Analyze/Measure

8. What is the diameter of the clear plastic portion of the CD in mm? Record your measurement in Table 1.
9. What is the area in mm^2 of the CD that is available to hold data ? Use your measurements for D_1 and D_2 in the equation for area (A) shown in the diagram.

Hopefully, the measurements you just made are both **precise** and **accurate**. To test this, you will make a series of measurements of the diameters of the inner and outer bands.

Precision is how closely repeated measurements match each other. **Accuracy** is how closely a measurement matches the correct value.

Use the straight line selection tool to select the diameter of the inner band (D_1) and outer band (D_2) of the CD to measure it two more times. Record your measurements in Table 1.

Analyze/Measure

Learn more about **precision** and **accuracy** in the Size and Scale module at http://invsee.eas.asu.edu/Modules/size&scale/Unit2/Unit2.htm

10. Calculate the area available to hold data using measurements #2 and #3 and record your answers in the Table 1.
11. What is the average value of the data storage area on the disc? Record your answer in Table 1.
12. If the actual data storing area on the disc is 8,750 mm^2, what is the percent error in your average value?

Use the magnifying glass tool to enlarge the image of the CD and repeat your measurements. Record them in Table 1.

13. What is the new average value of the data storage area? Record the value in Table 1.

$$\% \text{ Error} = \frac{|\text{Average Value} - \text{Actual Value}|}{\text{Actual Value}} \times 100$$

Hint: What factors might account for differences in precision? What factors might account for differences in accuracy?

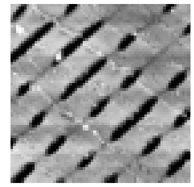
14. What is the percent error?
15. Are your new measurements more precise? Explain.
16. Are your new measurements more accurate? Why or why not?

Close all of the images.

File/Close

Size and Scale

Compact disc nano-technology



Lesson

In this lesson, you will examine the features on the surface of a compact disc (CD) that allow it to store digital, or binary, data. Magnifying the surface of the CD reveals important features that are invisible to the naked eye. A powerful magnifying tool called a scanning probe microscope (**SPM**) enables scientists and engineers to create clear three-dimensional views of the surface of the CD at nano-level scales.

Learn more about the **Scanning Probe Microscope** in the Theory and Simulation of SPM module at http://invsee.asu.edu
NEED TO PUT IN NON-FRAMES FORMAT, SO CAN GIVE URL TO DIRECTLY ACCESS MODULE

Section II. How do compact discs store information?

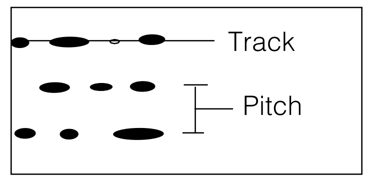
Zooming in

Open the image **CD I.jpg**. This image was created with an SPM.

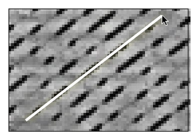
File/Open.../CD I.jpg

1. What do you see? Describe the features of the CD at this magnification.

The dark spots are arranged into linear patterns called **tracks**. The distance between two tracks is called the **track pitch**.



Use the straight line selection tool to drag a line through the middle of a series of dark spots along one track.



Create a plot profile of the image along this line. A plot profile is a representation of topography. The plot profile graph shows the depth, or “z values”, of the pixels along this line. There are 256 dark-to-light values in the “z” scale.

Analyze/Plot Profile

Compare the plot profile with the line selected along the image.

2. Are the dark spots high points or low points?

The low points in the plot profile are also called **pits** or indentations; the high points are called protrusions or **bumps**.

How is information stored in pits and bumps?

CDs contain digital, or binary, data. Binary data is represented in two states, a “0” or a “1”. Each “0” or “1” is one **bit** of information.

The term **bit** is an abbreviation of **bi**nary digi**t**.

The length of one edge of this image is 50 **micrometers** (µm). Use the tool to select the length along one edge and choose **Analyze/Set Scale...**. Enter the **Unit** of measurement and the **Known Distance** in the dialog box and click **OK**.

One **micrometer** is a thousand times smaller than a millimeter, one-millionth of a meter. Another name for micrometer is **micron**.

Choose **Edit/Select All** to select the entire image and choose **Analyze/Measure** to measure the area of this image.

The *ImageJ* window, shows measurements for the **area** of the image, the **mean** pixel value, the **standard deviation** of the pixel values, and the **minimum** and **maximum** pixel values.

3. What is the area of this image, in μm^2? Record your answer in Table 2 on the **Data Sheet**.
4. Approximately how many squares this size would fit on a quarter? And on a CD? Record your answer in Table 2. **Hint**: Use your calculation of the area of a quarter and a CD from the first section.

- Measure the lengths of several of the pits and spaces between the pits.

5. Are all the pits the same length? Are the spaces?

The length of each pit and the spaces between the pits are all multiples of one length. This is the length of one bit of information.

- Locate ten of the smallest pits on the image. Each of these indentations represents one bit of information.
- Measure and record the length of each of these pits in Table 3.

6. Calculate the average length of a bit from your measurements of the smallest pits in **CDI.jpg**? Record this in Table 3.

- Open the image **CDII.jpg** and and set the scale. The edge of this image is 20 µm.
- Measure the area of this image. Choose **Edit/Select All** and then **Analyze/Measure**. The *ImageJ* window, shows measurements for the area of the image.

7. What is the area of this image, in μm^2? Record this in Table 2.
8. Approximately how many squares this size would fit on a quarter? And on a CD? Use your data from Section I. Record this in Table 2.

- Measure the length of ten of the smallest pits in **CDII.jpg** and record in Table 3. Calculate and record the average.

9. How close is this to the first calculation of average bit length?

- Repeat for the other images, up to **CDV**. For each image, set a scale, measure its area and calculate how many would fit on a quarter. Record everything in Tables 2 and 3.

10. Can you accurately measure the bit length in all the images? Why or why not?

Use the tool to select the distance and choose **Analyze/ Measure.**

Use the tool to select the distance and choose **Analyze/ Measure.**

File/Open...CDII.jpg. Use the tool to select the length along one edge and choose **Analyze/Set Scale....** Enter the **Unit of measurement** and the **Known Distance** in the dialog box and click **OK.**

The length of one edge of the **CDIII** image is 10 µm, **CDIV** is 5 µm, and **CDV** is 1 µm.

How small in size are those pits and bumps?

- Open **hair.jpg**, **RedBloodCell.jpg** and **GraphiteAtoms.jpg**

11. What is the scale on the image of the hair, the red blood cell and the nickel atoms? Hint: Use the scale bar in each image to determine the scale.

- Set the scale for each image.

12. What is the diameter of each of these objects? Use the tool to select the distance and choose **Analyze/Measure**.
13. How does the size of each of these objects compare to the size of the CD data bits?
14. How many tracks would fit across the diameter of a human hair? A red blood cell?
15. How many graphite atoms would fit across a track? Hint: there are 10 000 Angstroms in a µm.

- Close all of the images.

File/Open...hair.jpg
...RedBloodCell.jpg
...GraphiteAtoms.jpg

Use the tool to select the length along one edge and choose **Analyze/Set Scale....** Enter the **Unit of measure-ment** and the **Known Dis-tance** in the dialog box and click **OK.**

Learn more about **metric conversions** in the Size and Scale module at http://invsee.eas.asu.edu/Modules/size&scale/Unit2/Unit2.htm

File/Close

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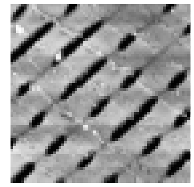
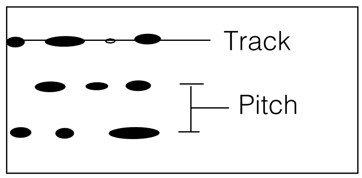


Lesson

III. How much data can you store on a disc?

In this lesson, you will determine the total amount of data that can be stored on a CD. Also, you will explore how a CD disc is manufactured. You have already determined how small each bit is, how are such nano-level features accurately duplicated on millions of disks? Then finally, how does a CD player "read" those pits and bumps to recreate the original information?

- Open the image **CDVI.gif** and set the scale. The edge of this image is 20 microns.
- Measure the pitch. Use the straight line selection tool to drag a line between two tracks. Choose **Analyze/ Measure**.



File/Open...CDVI.gif. Use the tool to select the length along one edge and choose **Analyze/Set Scale....** Enter the **Unit of measurement** and the **Known Distance** in the dialog box and click **OK.**

1. Each bit occupies a fixed amount of space on the disc, so the total available storage area determines the total amount of data that can be stored. Combine your measurement of the bit length (l) from Section II with the track pitch (w) to calculate the **area** covered by a single bit of information. What is the area of a bit?

Area = length (l) × width (w).

Every pit on the CD is slightly different, and the track pitch also varies, so the area you just calculated may not represent the average area of a bit. A more accurate way to measure the area of a bit is to count up the area covered by a large number of bits and then divide by the total area.

- Highlight the square selection tool and drag a 10 µm by 10 µm box over part of the image. Use the height and width values in the *ImageJ* window to make your selection accurate.
- Count the total number of bits in the box. Remember that some dark spots represent more than one bit of information, and that light spots in line with the dark spots are also bits.

To find the **area of a bit**, divide the total area of the square (10 μm^2) by the total number of bits. To find the **bit density**, divide the total number of bits by the area of the square.

$$\text{Area of bit} = \frac{\text{area of square}}{\text{total \# of bits}}$$

$$\text{Bit density} = \frac{\text{total \# of bits}}{\text{area of square}}$$

2. What is the area of a bit from this method? Is it larger or smaller than the area you calculated by measuring one bit?
3. What is the density of information on the CD, in bits per μm^2?
4. What is the total area available to hold data on the CD, in μm^2? (The area available to hold information on a CD is 8,750 mm^2.)
5. How many bits of information can be stored on a single CD?
6. If a byte is equal to 8 bits, how many bytes of information can be stored on a single compact disc?

Stamping out compact discs

To create the pits on the surface of a CD, engineers create a stamper. The stamper is exactly the same size and shape as the CDs it creates, but its vertical profile is inverted. In other words, a stamper has peaks where the CD has pits. Then, when the stamper is pressed onto a blank CD, it leaves behind pits in the surface of the CD.

- Watch the animation of the compact disc stamper producing a CD at http://invsee.asu.edu

7. Discuss the animation

File/Open.../CD Stamper IV.jpg

- Open the the image **CDStamperIV**.

Analyze/Plot Profile

- Use the straight line selection tool to drag a line through the middle of a series of dark spots on the stamper.
- Create a plot profile of the image along this line.

8. Are the bumps all at the same height?
9. Are the spaces between the peaks flat?

The height of the bumps determines the depth of the pits on the CD. Any imperfections in the stamper are directly transmitted to the CD.

10. If the height of the bump in this image is 200 **nanometers (nm)**, estimate the height of the smaller bumps at the bottom.

A **nanometer (nm)** is a thousand times smaller than a micron (µm).

An **angstrom (**symbol) is ten times smaller than a nanometer (nm).

A single atom of nickel is approximately 2 **angstroms (symbol)** across. Suppose that engineers could create a stamper that was so accurate it could stamp out a CD that had pits only one nickel atom long and a track pitch equal to two nickel atoms.

11. What is the area of this hypothetical bit?
12. How many bytes of information could fit on a CD stamped with this stamper?
    - Open the the images **StamperV.jpg and CD IV.jpg**.
    - Measure the area of a bit in each image.
13. Are the bits the same size? Why or why not?
    - Do a plot profile for along a track for each image.
14. How do the two plot profiles compare? Are the pits the same depth for both?
15. Are both the CD and the Stamper equally smooth? Why or why not?

How is a compact disc read?

Information is stored on a compact disc by burning or pressing small holes in the surface of the disc. As the disc spins, a small laser beam scans the surface of the disc. If there is no hole in the surface, the beam is reflected back into a detector, which records a zero. When the beam crosses a hole, it is not reflected and the detector registers a "1". So as the disc spins, the laser reader records a series of binary bits of information that represent pictures, sounds, numbers, or words.

Standard deviation is a measure of the average difference between a single measurement and the mean of all measurements.

- Watch the animation of the compact disc reader at http://invsee.asu.edu

16. Discuss the animation

To read the disc accurately, the spaces between the pits must be extremely smooth. If the surface is too rough, the beam will not be reflected and the reader will register ”1” where it should register “0”. One measure of the roughness is the **standard deviation** of the pixel values in the image. When a surface is smooth, the standard deviation of the pixel values is much smaller than the average pixel value.

- Open the image **CD V.jpg** and set the scale for the image. The length along one edge of the image is 1 µm.
- Highlight the square selection tool and drag a square across the upper part of the image, being careful to exclude the pit visible in the bottom half of the frame.
- Measure the area of the square. This measurement also reports the mean pixel value in the selected region and the standard deviation of the pixels.

17. What is the mean value of the pixels?
18. What is the standard deviation of the pixel values?
19. Is the standard deviation smaller or larger than the mean value?

- Highlight the square selection tool and drag a square across a part of the image that includes part of the pit visible in the bottom half of the frame.
- Measure the area of this square. This measurement also reports the mean pixel value in the selected region and the standard deviation of the pixels.

20. What is the mean value of the pixels in this square?
21. What is the standard deviation of the pixel values in this part of the image?
22. Is the standard deviation smaller or larger than the mean value?
23. Based on the definition of smooth as: “the standard deviation of the pixel values is much smaller than the average pixel value.” Is the surface smooth?

The laser light spot must be large enough to cover an entire bit, but small enough that it doesn’t read information from nearby bits.

24. Estimate the diameter of the laser spot.

- Close all images.

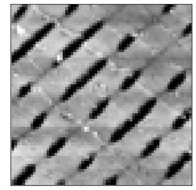
File/Open.../CD V.jpg. Use the tool to select the length along one edge and choose **Analyze/Set Scale....** Enter the **Unit of measurement** and the **Known Distance** in the dialog box and click **OK.**

Analyze/Measure

Analyze/Measure

File/Close

Size and Scale



Data Sheet

Name(s)____ Class______________

____ Date______________

Section I: What is size and what is scale?

1. Estimate how many quarters equal the diameter of the CD.

2. What is the diameter of the quarter, in millimeters?

3. How many numerical places (digits) are in your measurement? (This is the number of significant figures that any calculations you perform with this measurement can contain.)

4. To which numerical place is your measurement accurate?

5. What is the **area** of the quarter in square millimeters (mm^2)?

6. What is the diameter of a CD (D_2 as shown below) in millimeters? (How many significant figures can your measurement have?) Record this measurement in Table 1 below.
7. What is the area of the CD in square millimeters?

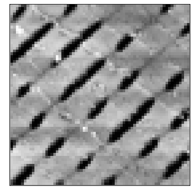
8. What is the diameter of the clear plastic portion of the CD, in millimeters? Record your measurement in Table 1.
9. What is the area in mm^2 of the CD that is available to hold data ? Use your measurements for D_1 and D_2 in the equation for area (A) shown in the diagram.

Table 1

Measurement trial	Diameter of inner band (D1)	Diameter of outer band (D2)	Area (A) of data storage	Average area value
No magnification				
#1				
#2				
#3				
With magnification				
#1				
#2				
#3				

10. Calculate the area available to hold data using measurements #2 and #3 and record your answers in the Table 1.
11. What is the average value of the data storage area on the disc? Record your answer in Table 1.
12. If the actual data storing area on the disc is 8,750 mm^2, what is the percent error in your average value?
13. What is the new average value of the data storage area? Record the value in Table 1.
14. What is the percent error?
15. Are your new measurements more precise? Explain.
16. Are your new measurements more accurate? Why or why not?

Size and Scale



Data Sheet

Name(s)____ Class______________

____ Date______________

Section II: How do compact discs really work?

1. What do you see? Describe the features of the CD at this magnification.

2. Are the dark spots high points or low points?

3. What is the area of this image, in μm^2? Record your answer in Table 2 below.

Table 2: Measurements of information density

Image	Area (μm^2)	# per quarter	# per CD
CD I			
CD II			
CD III			
CD IV			
CD V			

4. Approximately how many squares this size would fit on a quarter? And on a CD? Record your answer in Table 2.

5. Are all the pits the same length? Are the spaces?

6. Calculate the average length of a bit from your measurements of the smallest pits in **CDI.jpg**? Record this in Table 3.

Table 3: Measurements of 10 smallests bits' lengths for each image

	CD I	CD II	CD III	CD IV	CD V
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Average					

7. What is the area of this image, in μm^2? Record this in Table 2.
8. Approximately how many squares this size would fit on a quarter? And on a CD?

9. How close is this to the first calculation of average bit length?

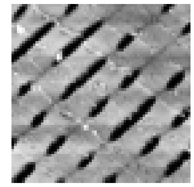
10. Can you accurately measure the bit length in all the images?
11. What is the scale on the image of the hair, the red blood cell and the nickel atoms?
    Hair:
    Red blood cell:
    Nickel atoms:
12. What is the diameter of each of these objects?
    Hair:
    Red blood cell:
    Nickel atoms:
13. How does the size of each of these objects compare to the size of the CD data bits?

14. How many tracks would fit across the diameter of a human hair? A red blood cell?

15. How many nickel atoms would fit across a track?

Size and Scale

Compact disc nano-technology



Data Sheet

Section III: How much data can you store on a disc?

1. What is the area of a bit?

2. What is the area of a bit from this method?

3. What is the density of information on the CD, in bits per μm^2?

4. What is the total area available to hold data on the CD, in μm^2?

5. How many bits of information can be stored on a single CD?

6. If a byte is equal to 8 bits, how many bytes of information can be stored on a single compact disc?

7. Question about animation???????

8. Are the bumps all at the same height?

9. Are the spaces between the peaks flat?

10. If the height of the bump on this image is 200 nanometers, estimate the height of the smaller bumps at the bottom.

11. What is the area of this hypothetical bit?

12. How many bytes of information could fit on a CD stamped with this stamper?

13. Are the bits the same size? Why or why not?

14. How do the two plot profiles compare? Are the pits the same depth for both?

15. Are both the CD and the Stamper equally smooth? Why or why not?

16. Question about animation?????

17. What is the mean value of the pixels?

18. What is the standard deviation of the pixel values?

19. Is the standard deviation smaller or larger than the mean value?

20. What is the mean value of the pixels in this square?

21. What is the standard deviation of the pixel values in this part of the image?

22. Is the standard deviation smaller or larger than the mean value?

23. Based on the definition of smooth as: "the standard deviation of the pixel values is much smaller than the average pixel value." Is the surface smooth?

24. Estimate the diameter of the laser spot.