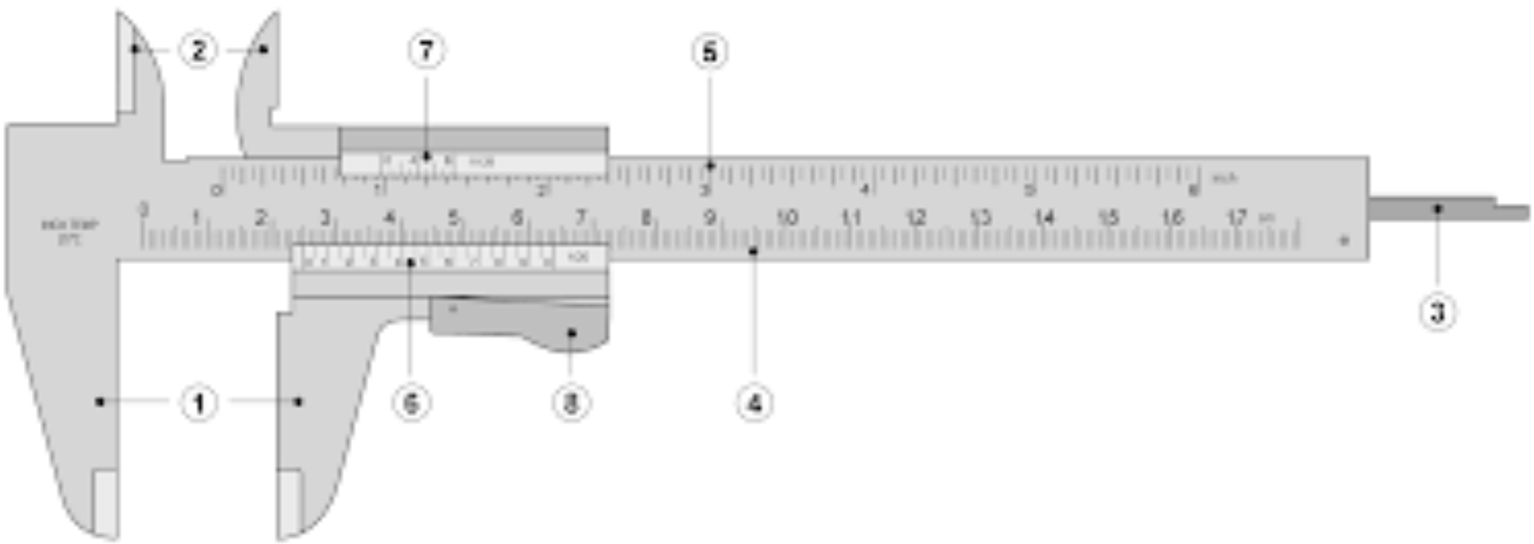
Lab 1 Appendix:
Examples of Resolution Error for Rulers, Calipers, and Micrometers



Definition of Resolution

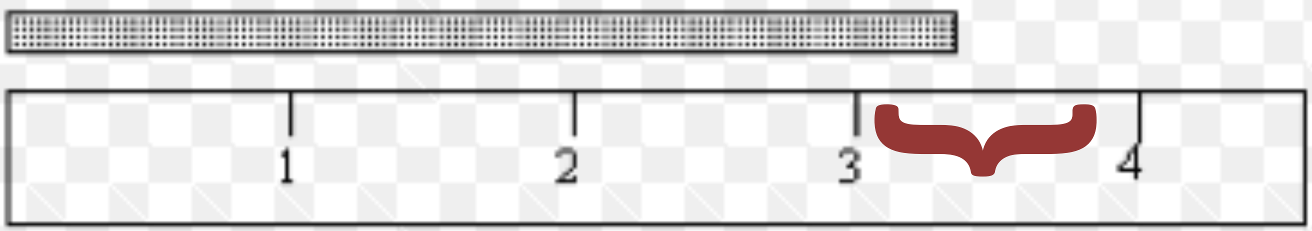
Resolution is the incremental ability of a measurement system to discriminate between measurement values.

The measurement system should have a **minimum of 20 measurement increments** within the product tolerance (e.g, for a full tolerance of 1, minimum resolution is .05)

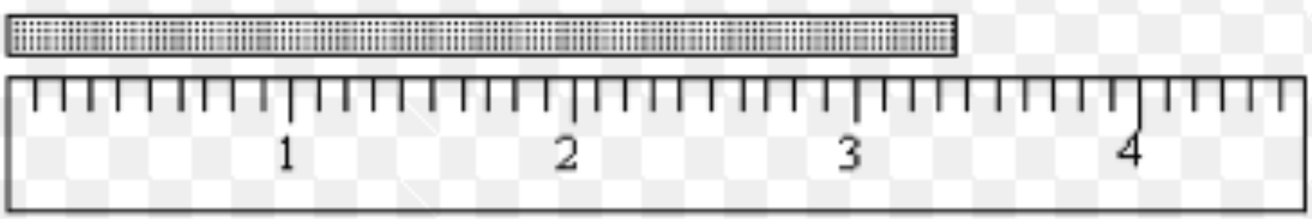
Resolution of a Conventional Ruler

Measuring the length of a rod with coarse and fine rulers.

On a ruler with a coarse scale, the rod is between 3 and 4 cm, and we estimate it to be about 3.3 cm. The instrument least count is 1 cm.

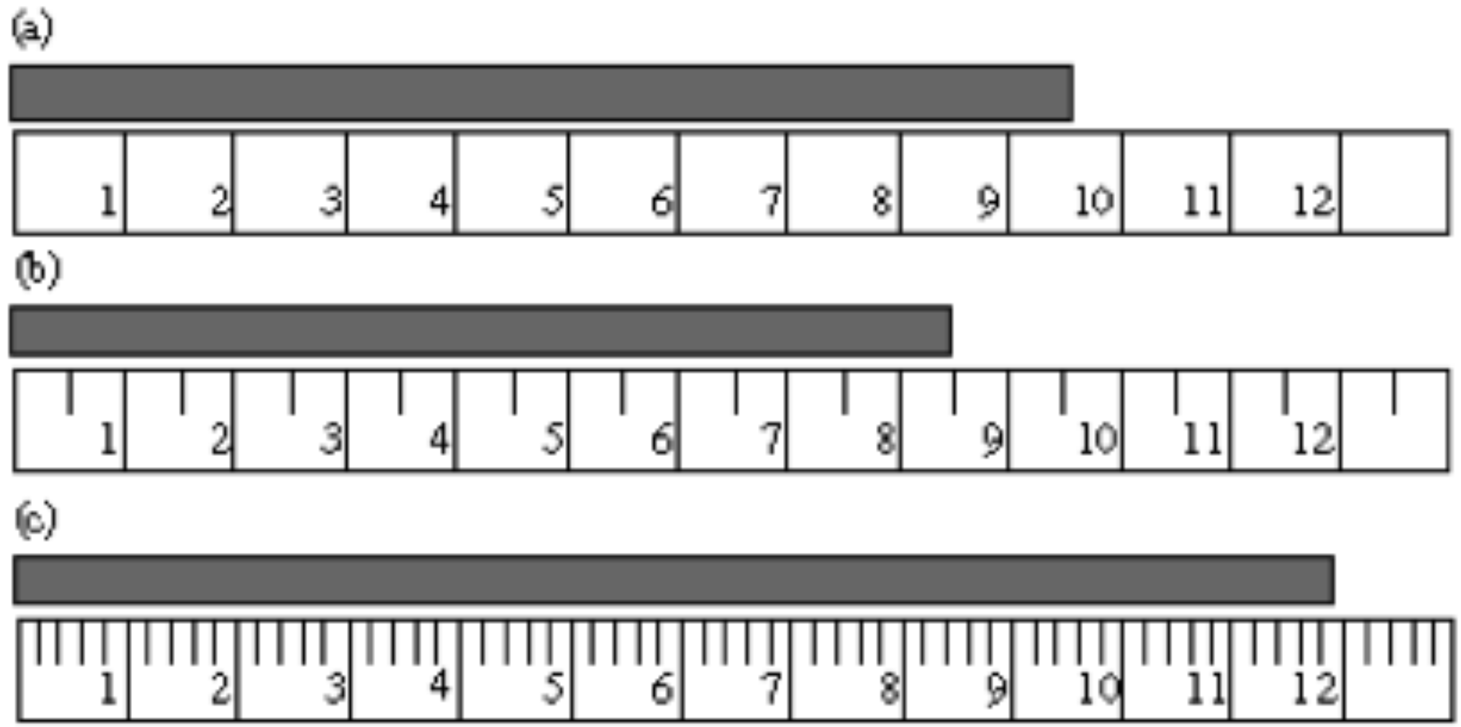


On a ruler with a finer scale the rod is between 3.3 and 3.4 cm, and we estimate it to be about 3.38 cm. Instrument least count is 0.1 cm.



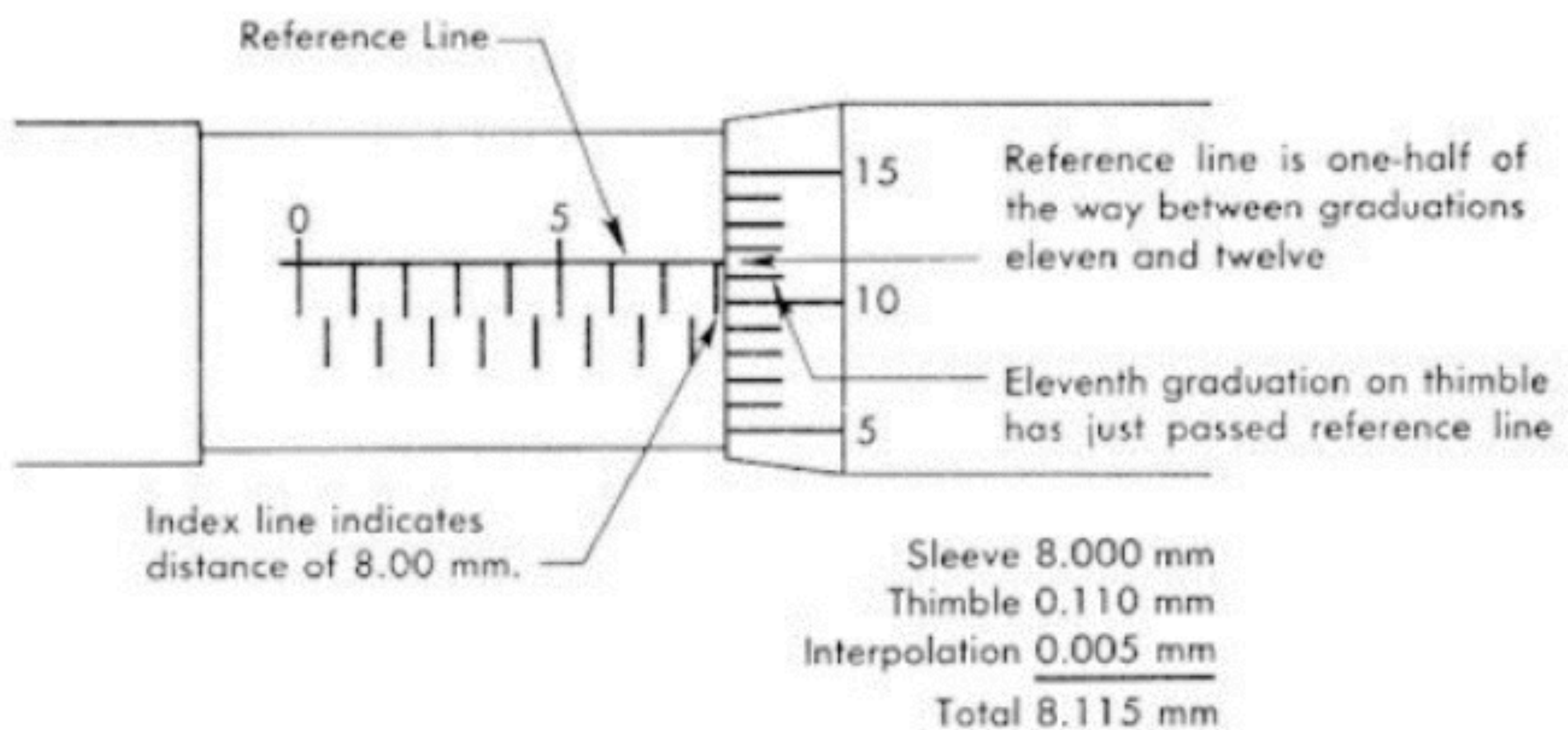
Count … Minimum Quantifiable Change in Scale Reading

Resolution of a Conventional Ruler (2)



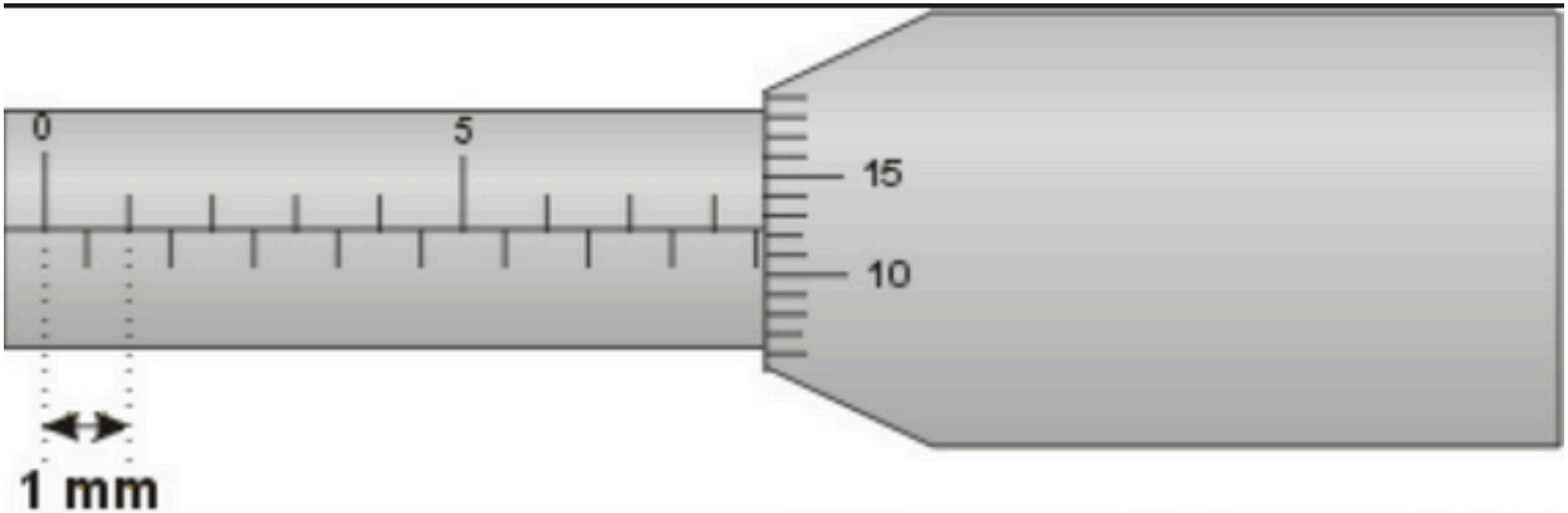
For these three Rulers , what are Readings and Resolution Errors (Least Significant Digit Increment)

Micrometer Resolution



Resolution ~± 0.005

Micrometer Resolution (2)



- Depending on your eyes and screen resolution, you might be fairly confident that the reading is less than, say, 8.627 mm and similarly confident that it is greater than 8.621 mm. Thus you might assign a *Reading Error* to this measurement of 0.003 mm
- So, we would report the distance as **8.624 ± 0.003** mm.

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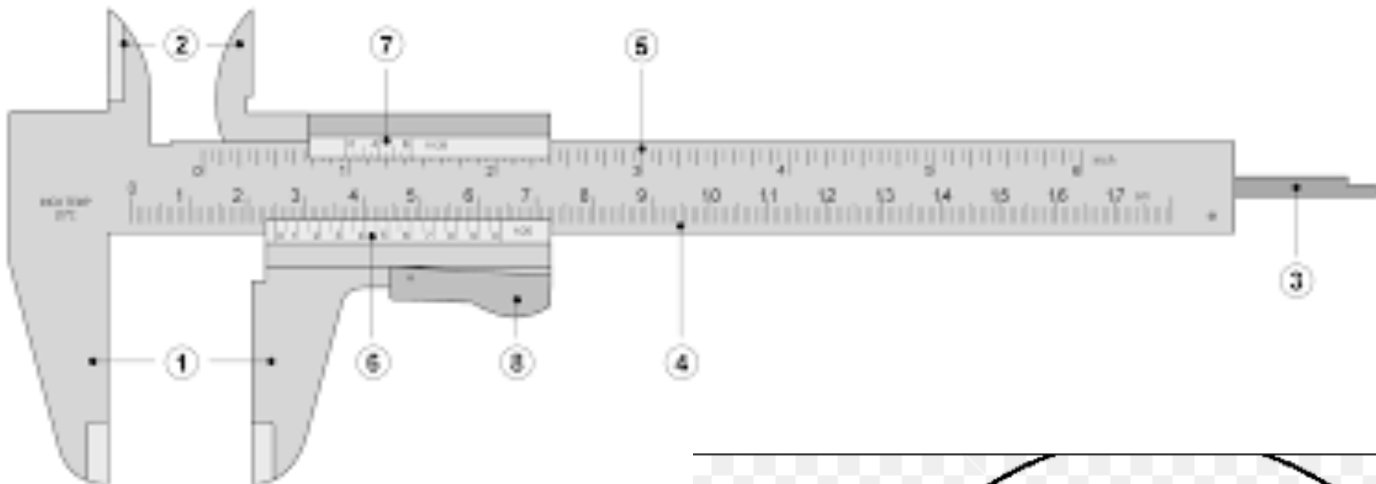
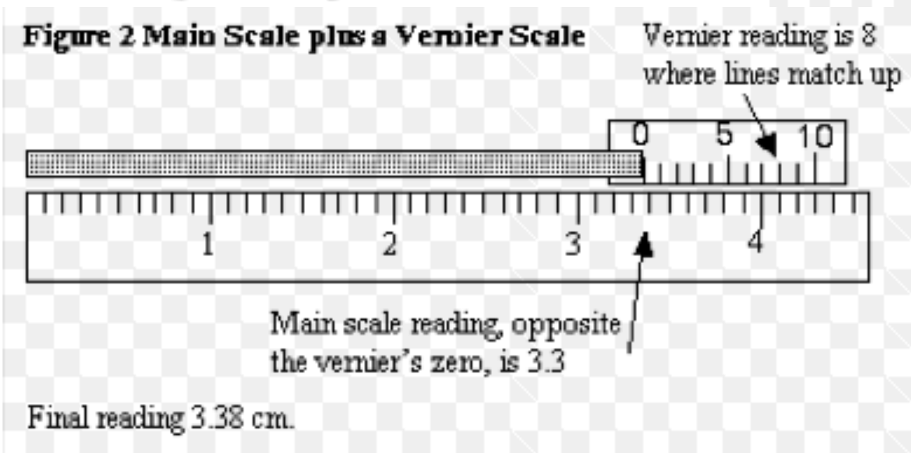
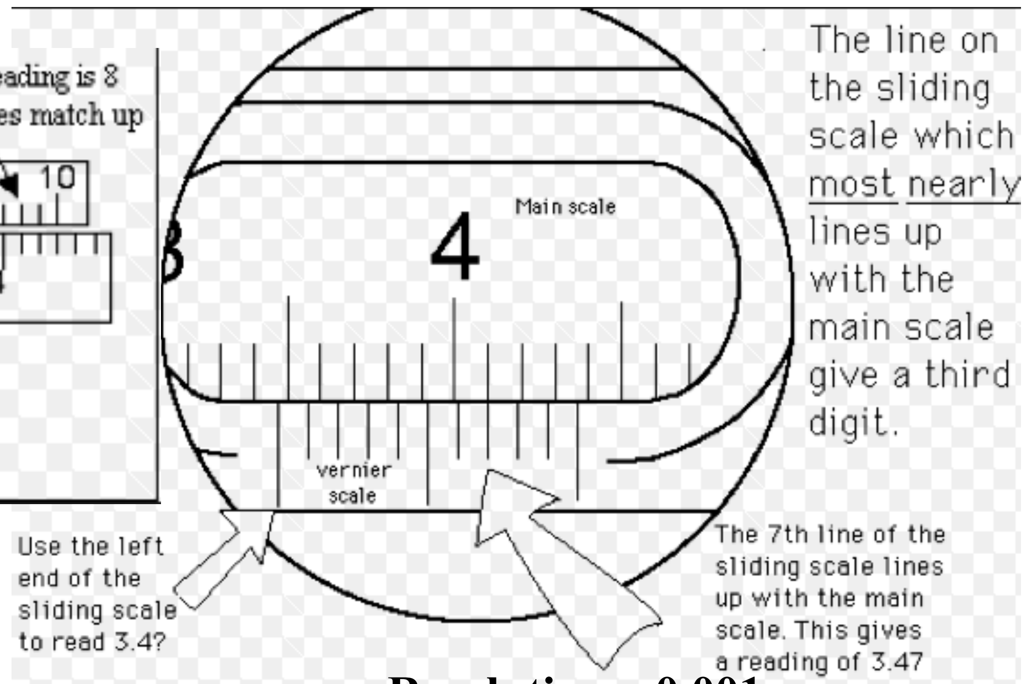
Vernier Caliper Resolution



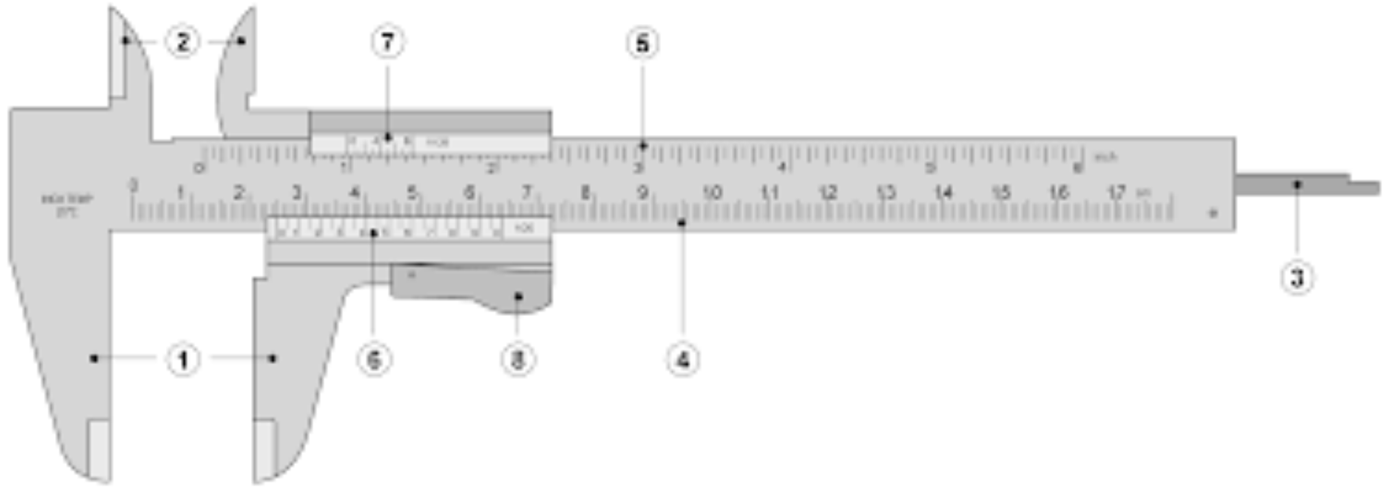


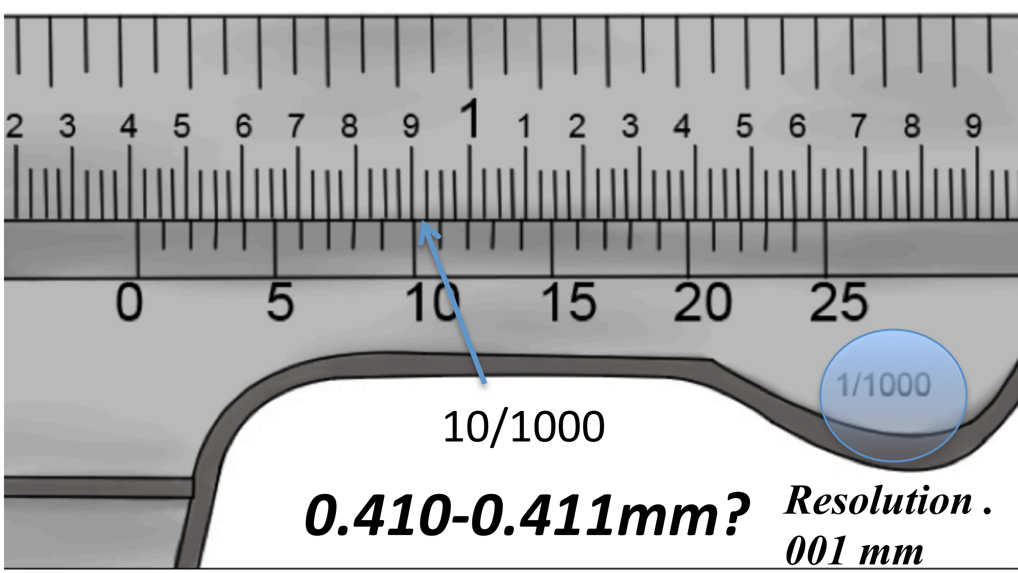


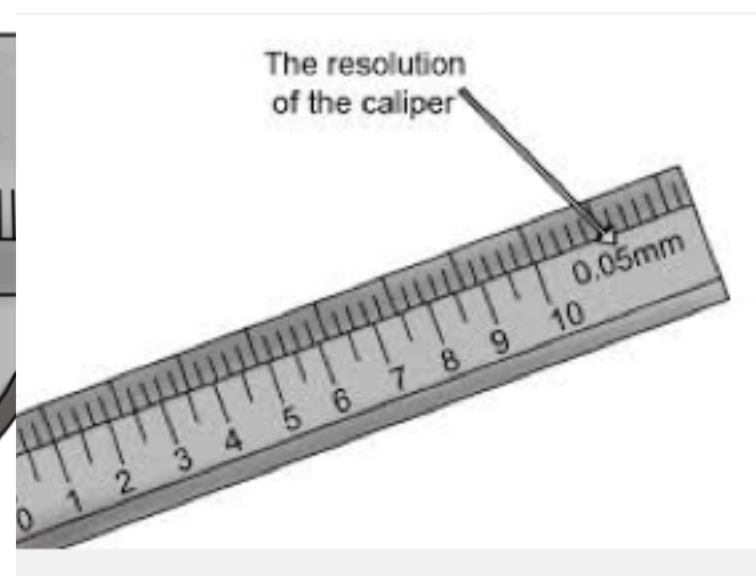
Resolution ~ 0.01 cm

Resolution ~ 0.001 mm

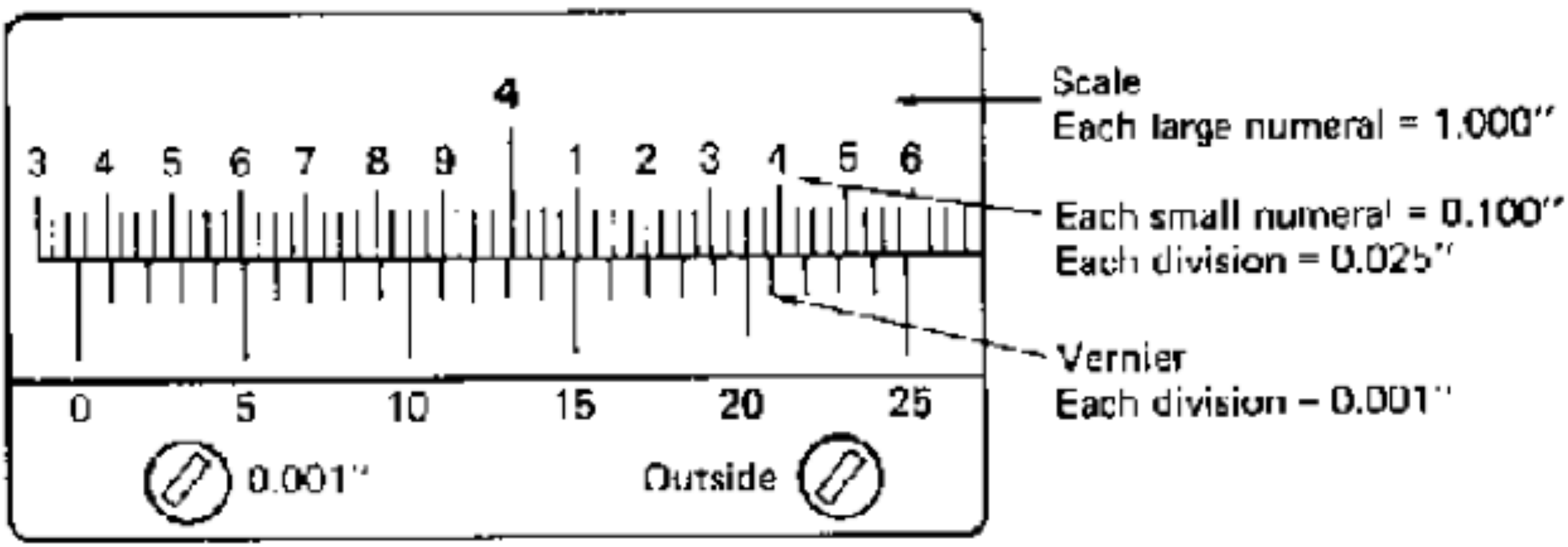
Vernier Caliper Resolution (2)







Vernier Caliper Resolution (3)



Last large-scale numeral	3.000"
Last small-scale numeral	0.300"
Each scale division past 3 2 × 0.025"	0.050"
Number of vernier graduations that coincides with a scale graduation	0.020"
Total	3.370"

Resolution .
0.001 "

Least Significant Digit Increment and Resolution Error

$U_{resolution}$ ~ +0.001

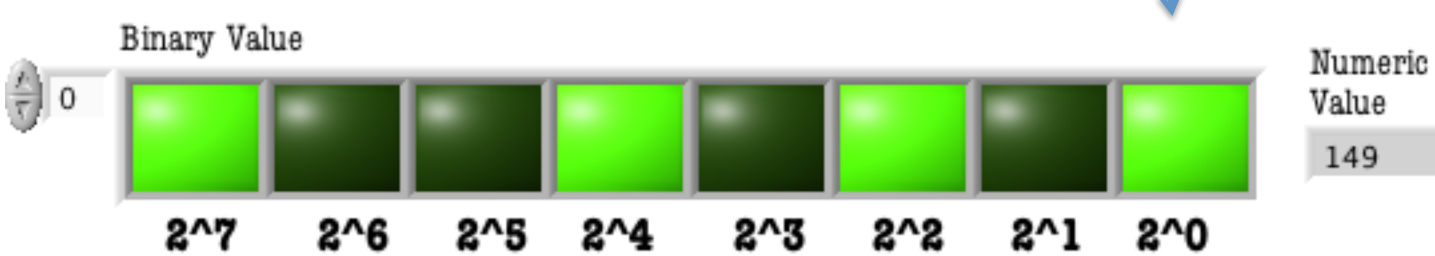
For this electronic caliper what is the least significant digit increment (resolution error)

Binary Representation of a Number

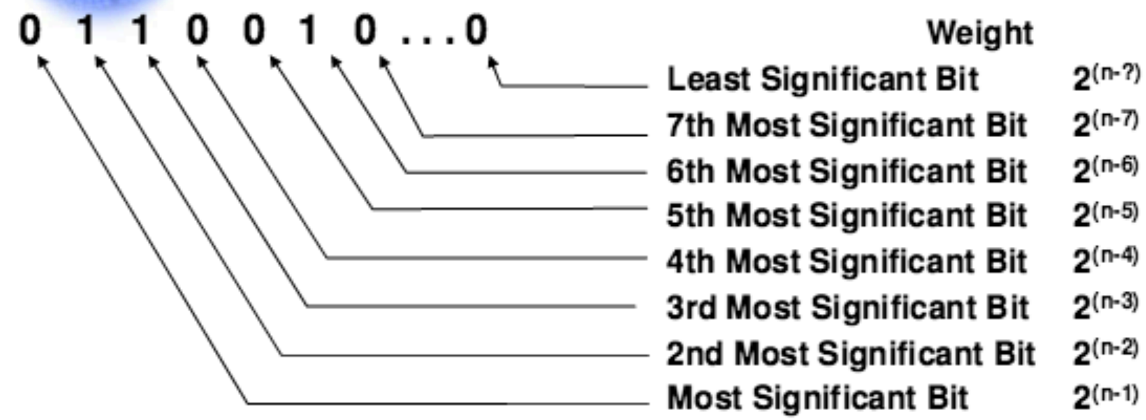
The binary representation of decimal 149, with the LSB highlighted. The MSB in an 8-bit binary number represents a value of 128 decimal. The LSB represents a value of 1.

Least Significant Bit

$$2^7 + 0 + 0 + 2^4 + 0 + 2^2 + 0 + 2^0 \qquad = 149$$



Least Significant Bit (LSB) and Most Significant Bit (MSB)



Bit Weights of an 8-Bit Word

MSB							LSB
B7	B6	B5	B4	B3	B2	B1	B0
128	64	32	16	8	4	2	1

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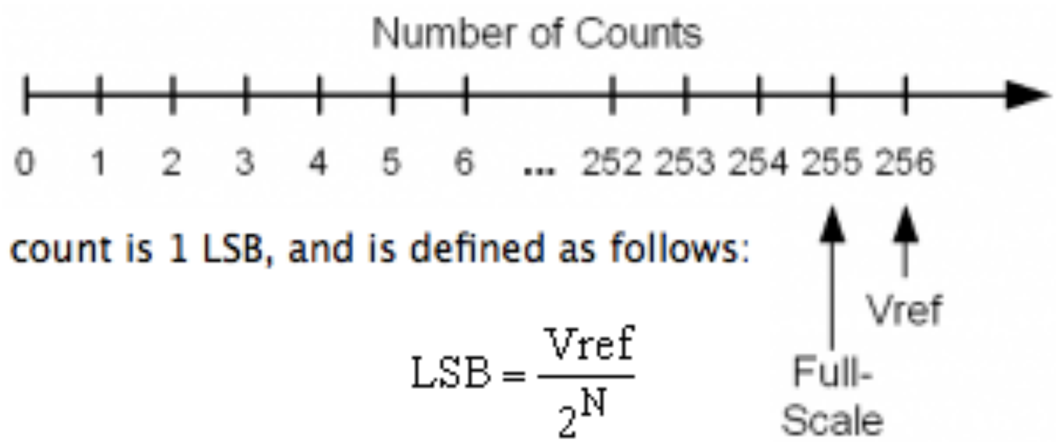
The Least and Most Significant Bits (LSB and MSB) are just what their name implies: those bits that have the least weight (LSB) and most weight (MSB) in a digital word. For an n-bit word, the MSB has a weight of $2^{(n-1)} = 2^n / 2$ where "n" is the total number of bits in the word. The LSB has a weight of 1.

Binary Representation of a Measured Voltage by an "Analog to Digital Conversion" (ADC)

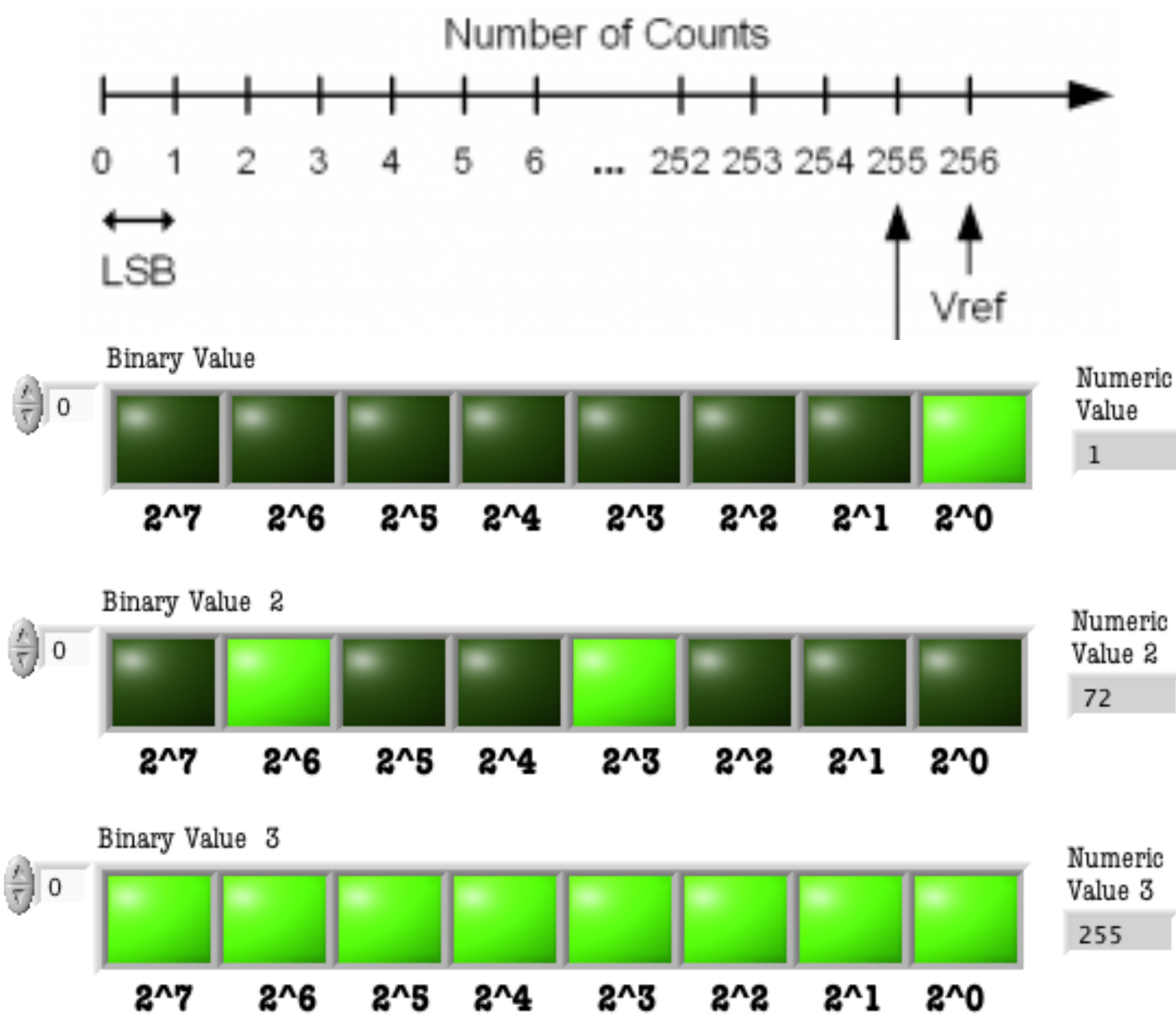
The ADC needs a voltage reference to convert an analog signal into a digital word. Depending on the number of bits it has, the ADC divides the voltage reference in small levels called counts. For example, if this is an 8-bit ADC, the counts will look like those in Figure 1. In an 8-bit ADC there are 2^8 = 256 counts.



One count is 1 LSB, and is defined as follows:

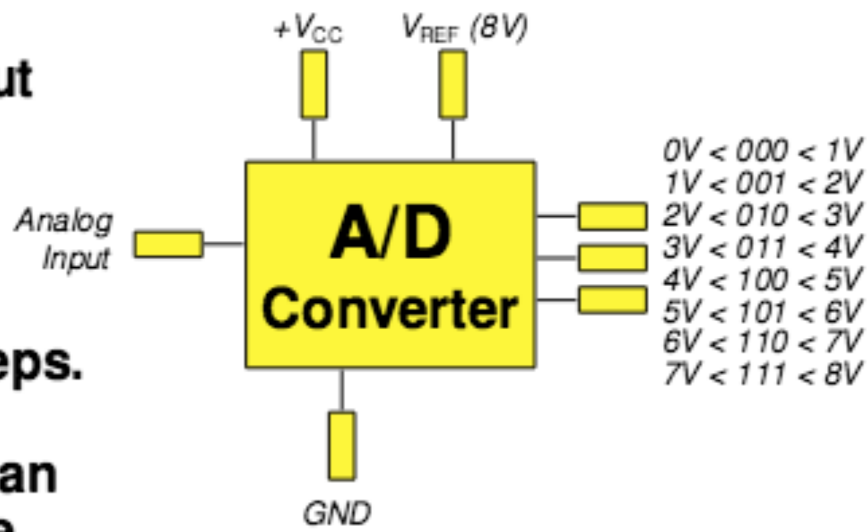
$$LSB = \frac{Vref}{2^N}$$

"Analog to Digital Conversion" (2)



"Analog to Digital Conversion" (3)

- For a 3-bit ADC, there are 8 possible output codes.
- In this example, if the input voltage is 5.5V and the reference is 8V, then the output will be 101.
- More bits give better resolution and smaller steps.
- A lower reference voltage gives smaller steps, but can be at the expense of noise.



$$LSB = \frac{V_{\max_{ADC}} - V_{\min_{ADC}}}{2^3} = \frac{(8-0)V}{8} = 1V / count$$

$$Max\ counts = 2^3 = 8$$

$$V_{discrete} = Int\left[\left(\frac{V_{analog} - V_{\min_{ADC}}}{V_{\max_{ADC}} - V_{\min_{ADC}}}\right) \times Max\ counts\right] + V_{\min_{ADC}} = Int\left[\left(\frac{5.5-0}{8-0}\right) \times 8\right] = 5 + 0 = 5V$$

$$\boxed{2^2 + 0 + 2^0 = 5} \rightarrow 101_{binary}!$$

"Analog to Digital Conversion" (3)