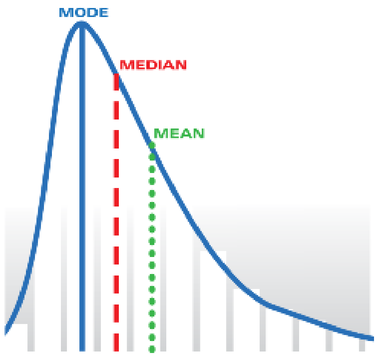
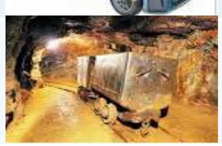
Introduction to Particle Size Analysis



Jeff Bodycomb, Ph.D.
jeff.bodycomb@horiba.com
www.horiba.com/us/particle

Why Particle Size?

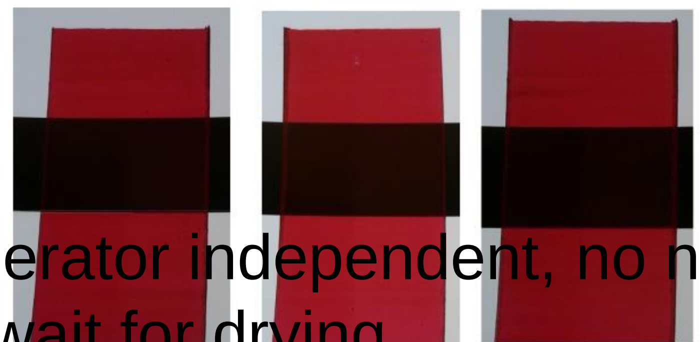
Size affects material behavior and processing across a number of industries.

Industry		Industry	
Ceramic	 	**Construction**	
Oil/rubber	 	**Chemical**	
Battery		**Pharmaceutical**	
Electricity		**Food/Drink**	 
Automobile		**Paper/Pulp**	 
Mining		**Ink/Toner**	 

© 2018 HORIBA, Ltd. All rights reserved.

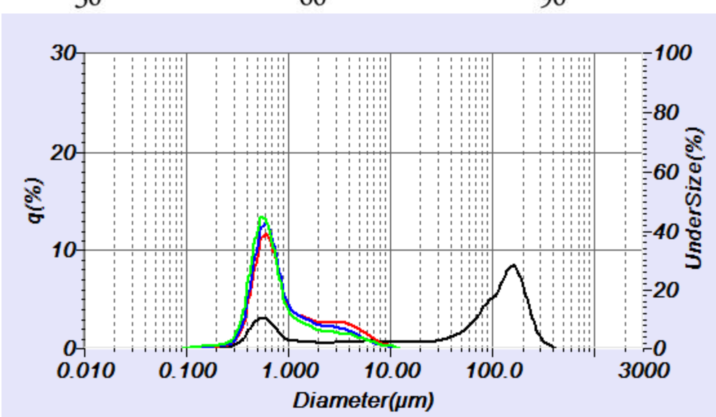
Application: Pigment Hiding Power

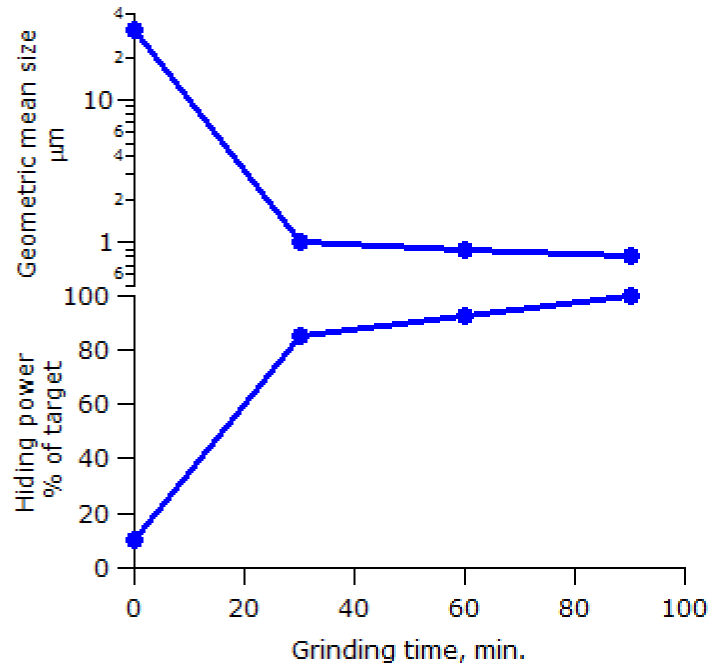
Operator dependent, need to wait for drying.



Operator independent, no need to wait for drying.

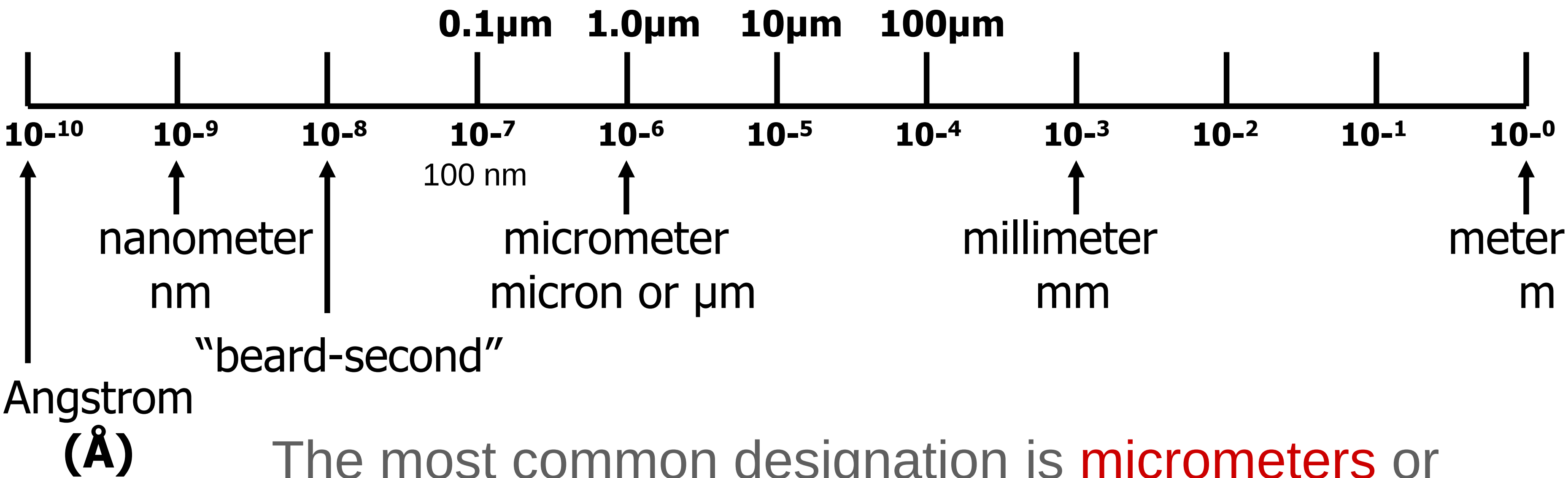
30 60 90





© 2018 HORIBA, Ltd. All rights reserved.

Size Terminology



C-H bond length

The most common designation is micrometers or microns. When very small, in colloid region, measured in nanometers, with electron microscopes or by dynamic light scattering.

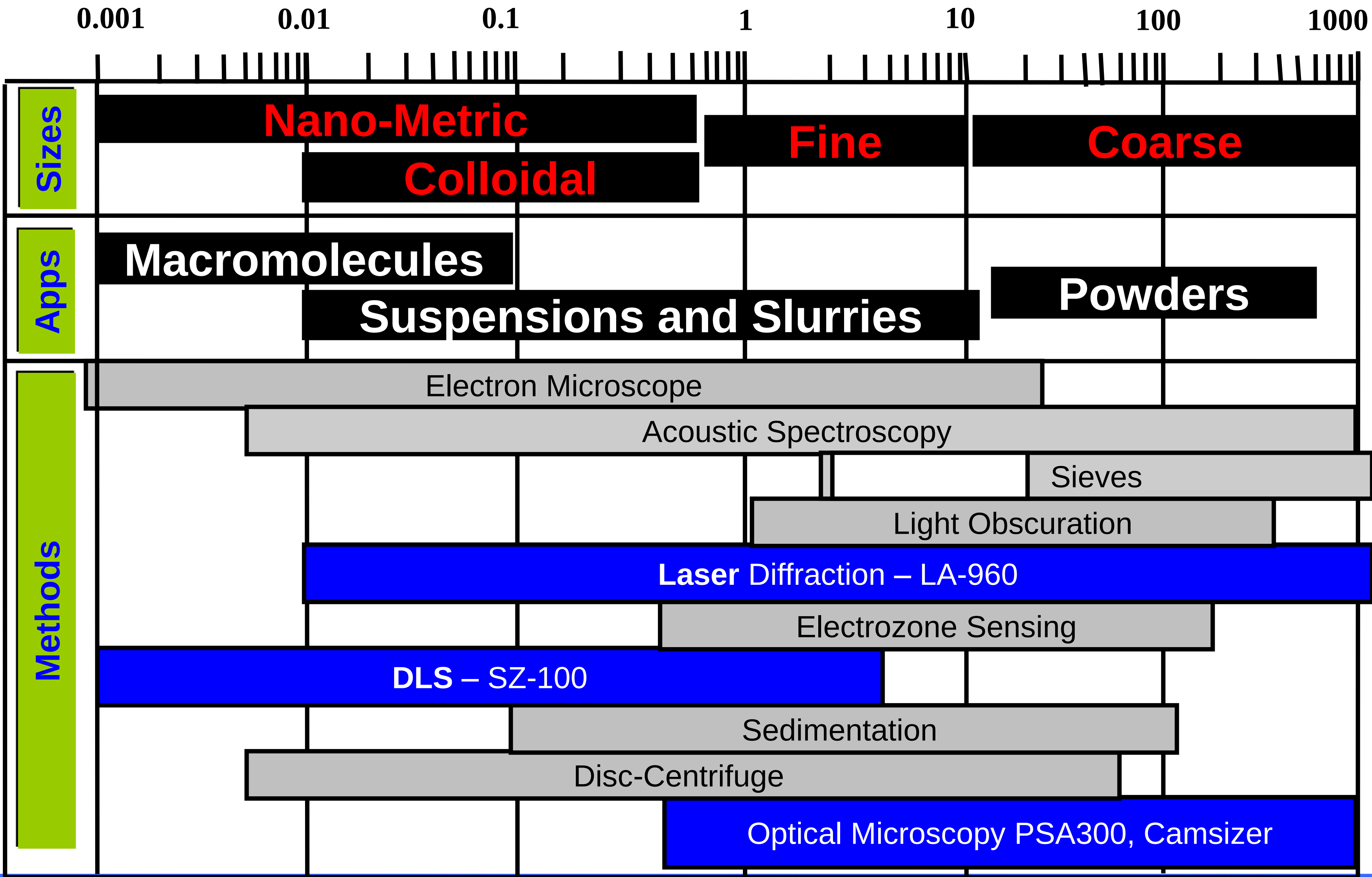
Fun tip: Describing your work in terms of beard-seconds make it much more interesting at parties.

© 2018 HORIBA, Ltd. All rights reserved.

Poll!

Which size ranges do you measure?

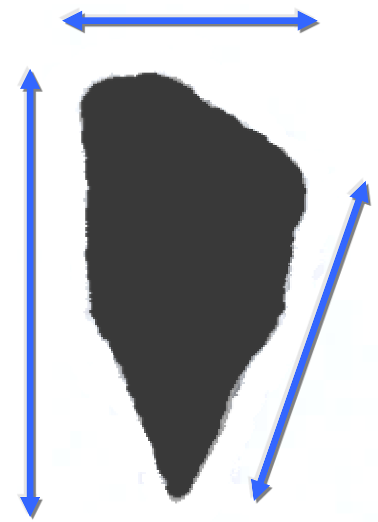
Size: Particle Diameter (µm)



© 2018 HORIBA, Ltd. All rights reserved.

The Basics

Which is the most meaningful size?

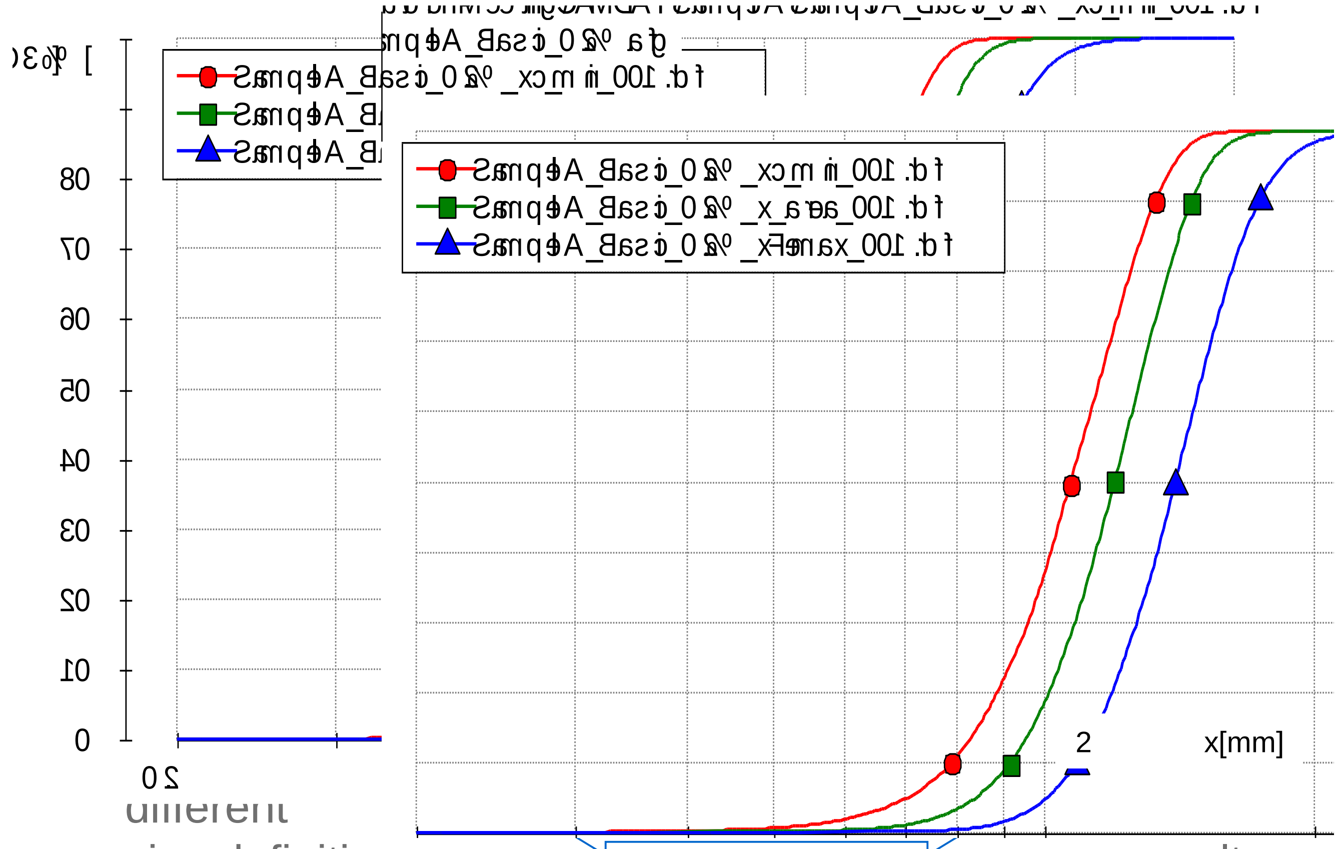


different size definitions → **different results**

© 2018 HORIBA, Ltd. All rights reserved.

Same data, different size definitions give different results!

$x_{c\,min}$ ⇔ x_{Area} ⇔ $x_{Fe\,max}$



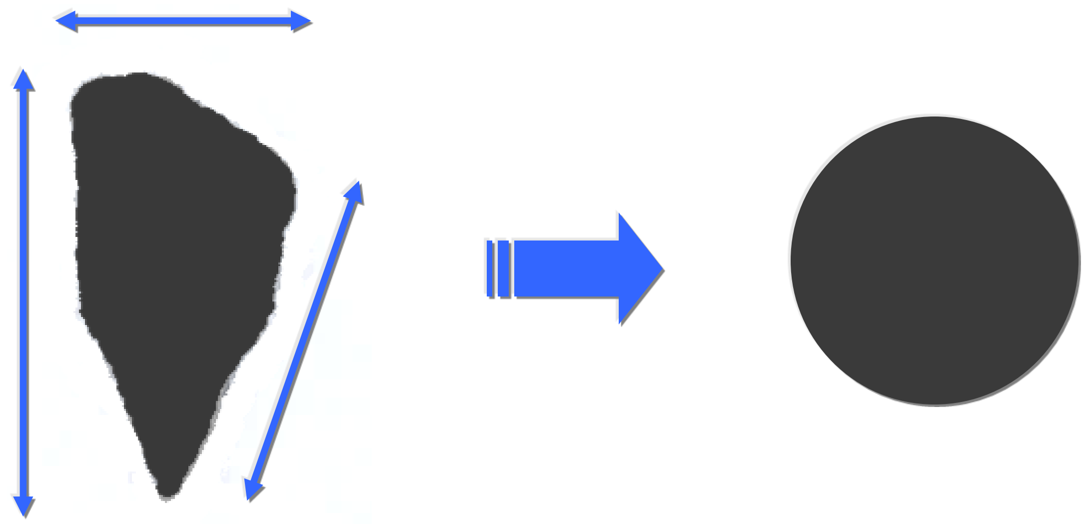
size definitions

results

© 2018 HORIBA, Ltd. All rights reserved.

The Basics

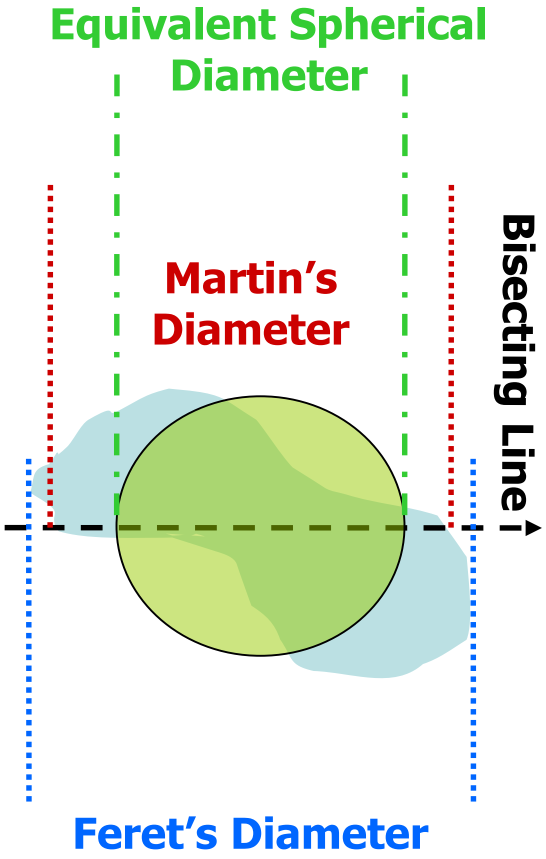
What sizes can be measured?



© 2018 HORIBA, Ltd. All rights reserved.

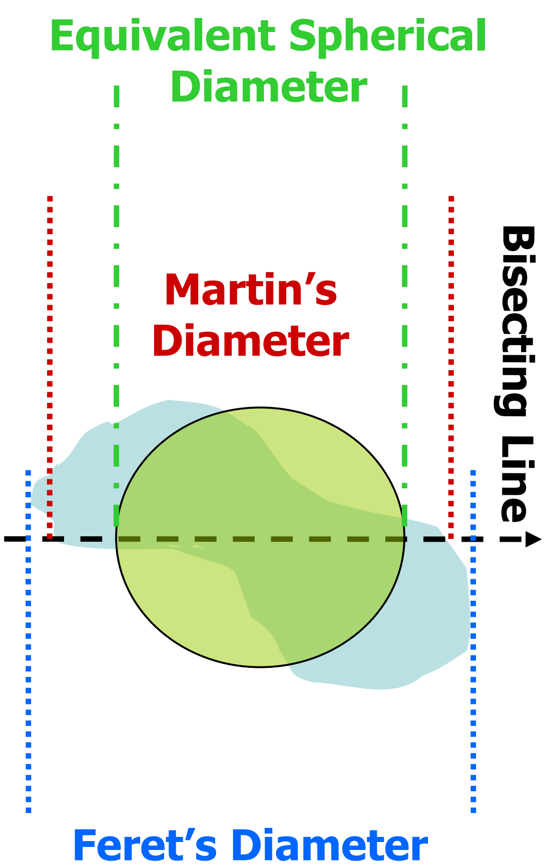
Size Definitions

- **<u>Martins's Diameter:</u>** The distance between opposite sides of a particle measured on a line bisecting the projected area. To ensure statistical significance all measurements are made in the same direction regardless of particle orientation.
- **<u>Feret's Diameter:</u>** The distance between parallel tangents on opposite sides of the particle profile. Again to insure statistical significance, all measurements are made in the same direction regardless of particle orientation.
- **Note:** *Both Martin's and Feret's diameters are generally used for particle size analysis by optical and electron microscopy.*
- **<u>Equivalent Circle Diameter:</u>** The diameter of a circle having an area equal to the projected area of the particle in random orientation. This diameter is usually determined subjectively and measured by oracular micrometers called graticules.
- **<u>Equivalent Spherical Diameter:</u>** The diameter of a sphere that has the same volume as the irregular particle being examined.

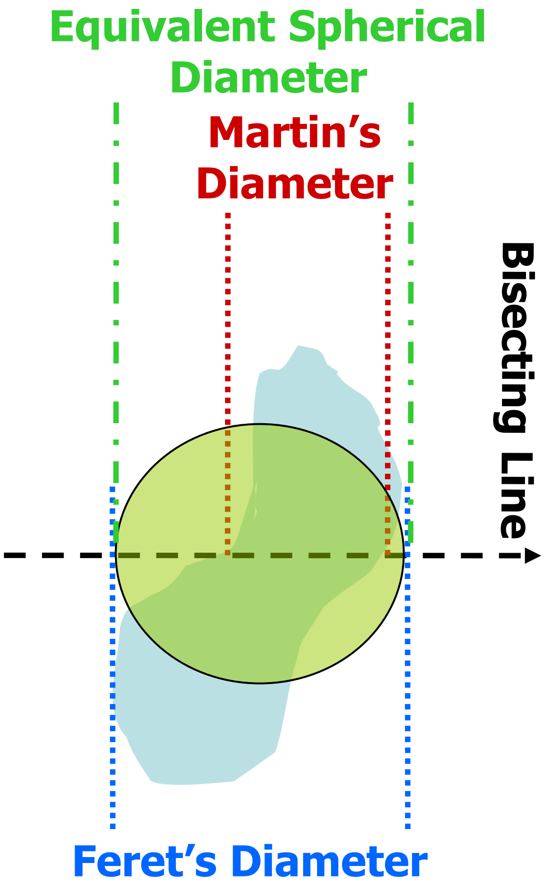


© 2018 HORIBA, Ltd. All rights reserved.

Particle Orientation



- **Martin's and Feret's Diameter's will vary as particles are viewed in different orientations. The result will be a DISTRIBUTION from smallest to largest.**

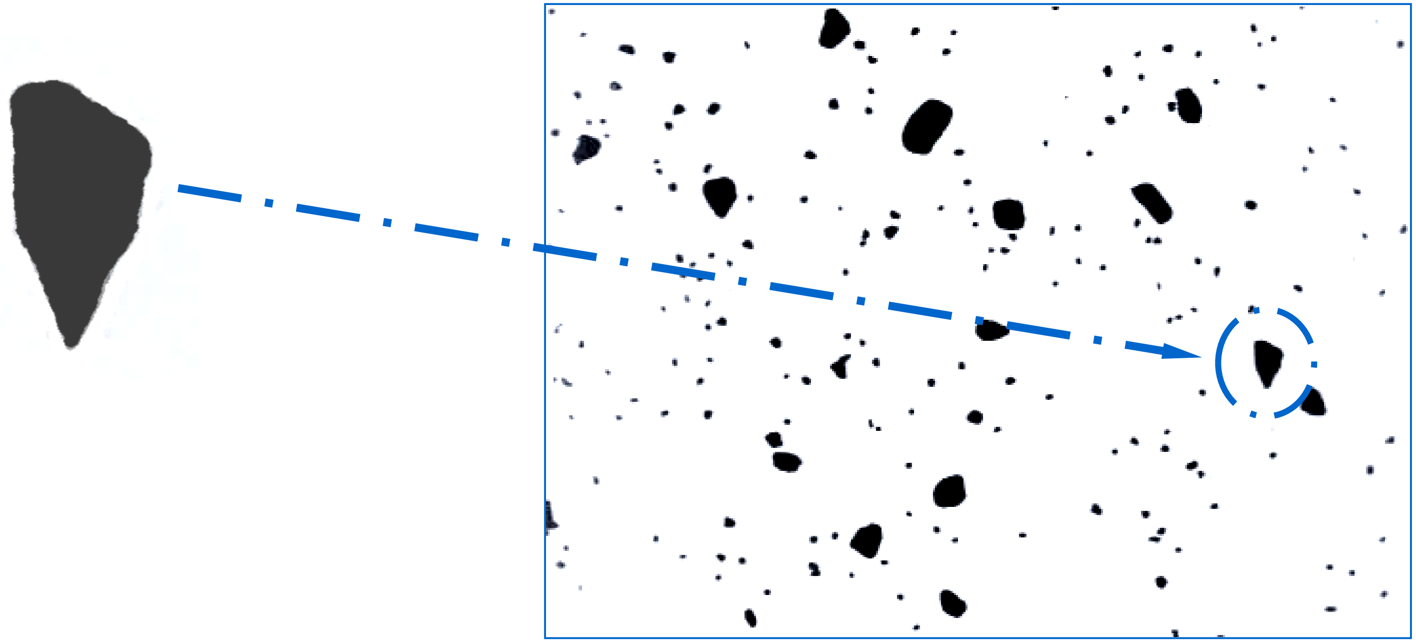


© 2018 HORIBA, Ltd. All rights reserved.

The Basics

Particle

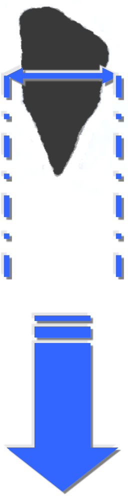
Particle Distribution



© 2018 HORIBA, Ltd. All rights reserved.

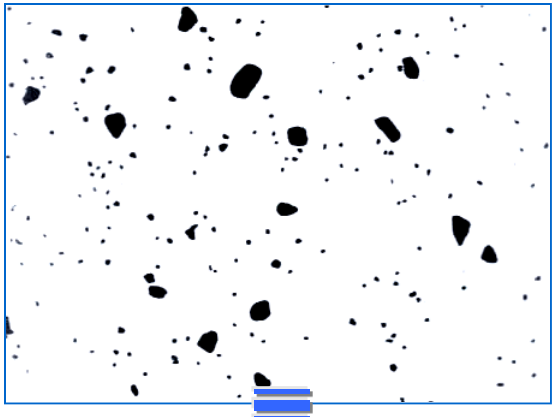
The Basics

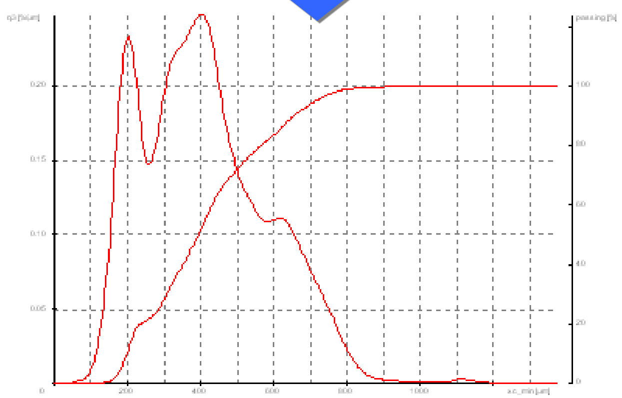
Particle Size



4 µm

Particle Size Distribution





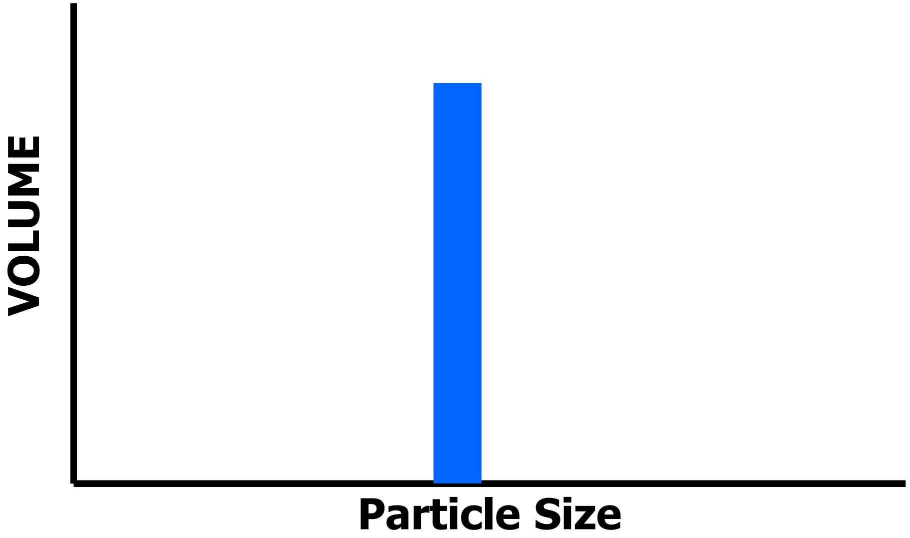
© 2018 HORIBA, Ltd. All rights reserved.

Poll!

What size(s) are reported by your PSA?

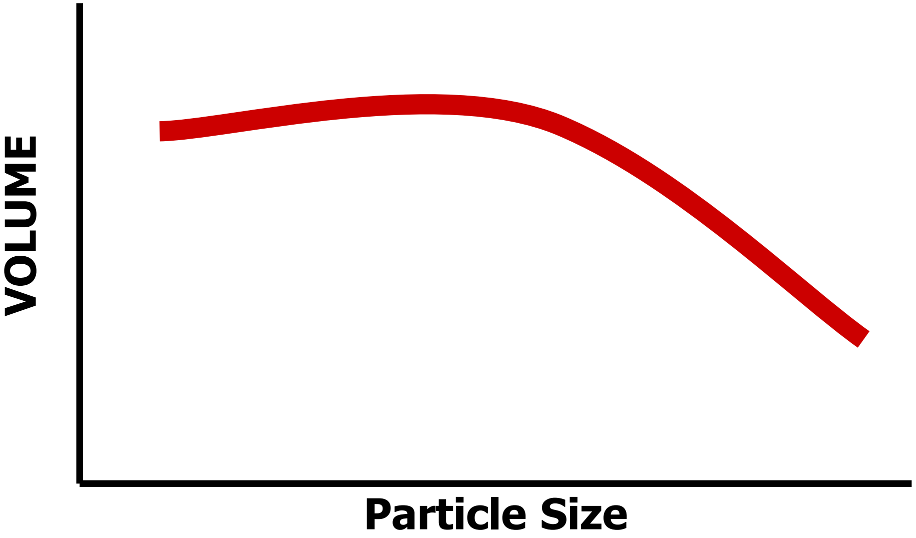
Monodisperse vs. Polydisperse

Monodisperse



- **Monodisperse Distribution:**
  - All particles are the same size
  - Latex standards

Polydisperse

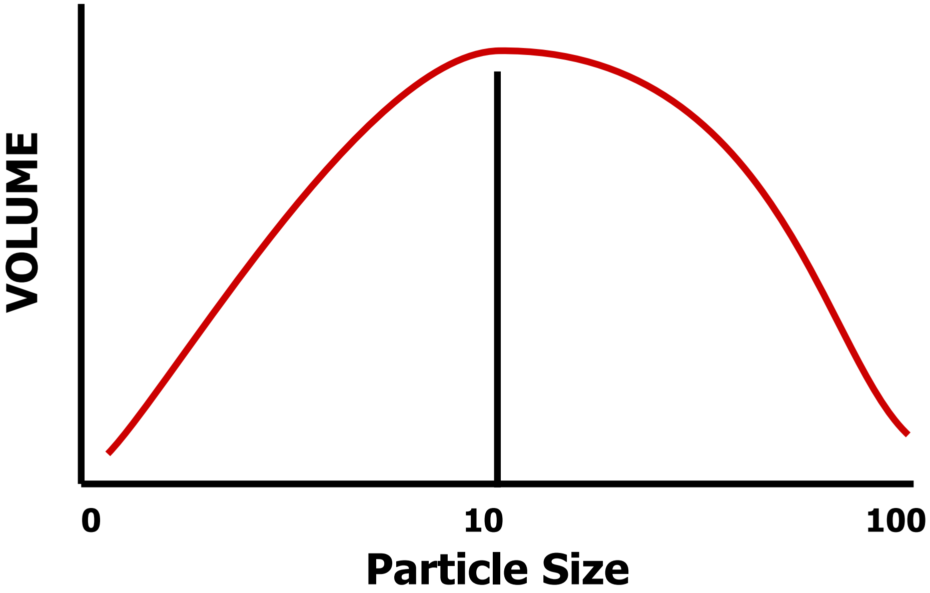


- **Wide Distribution:**
  - Particles of Many Sizes
  - Everything else

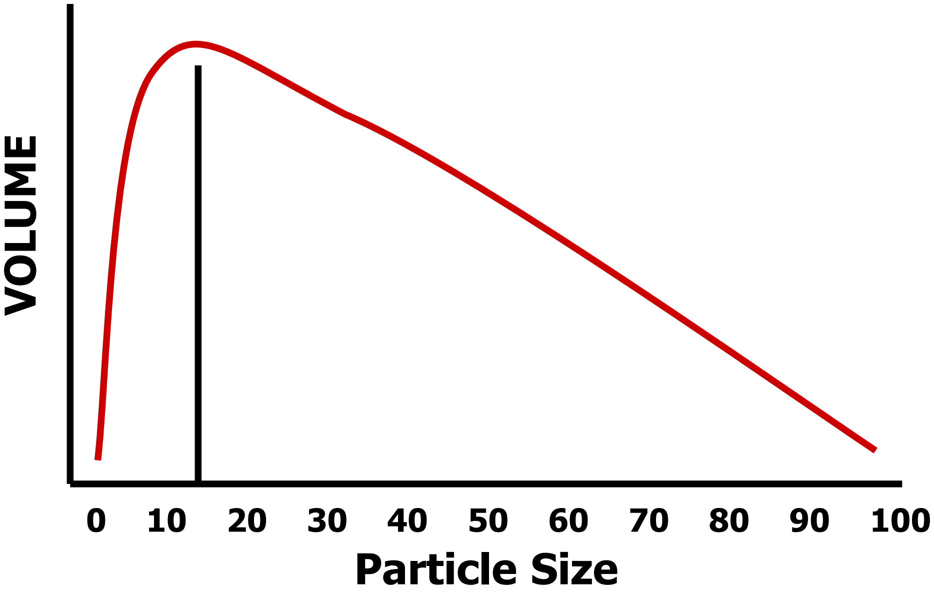
© 2018 HORIBA, Ltd. All rights reserved.

Logarithmic vs. Linear Scale

- Logarithmic X-Axis Distribution

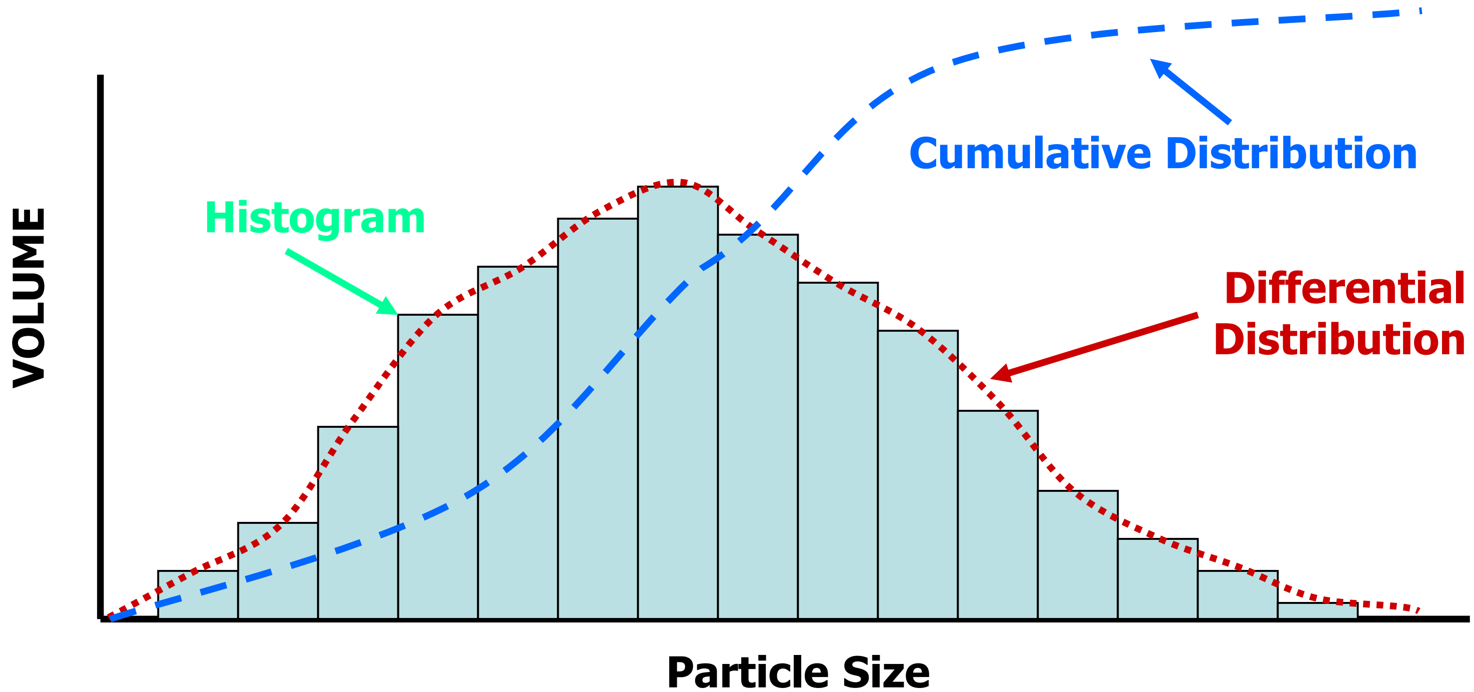


- Linear X-Axis Distribution



© 2018 HORIBA, Ltd. All rights reserved.

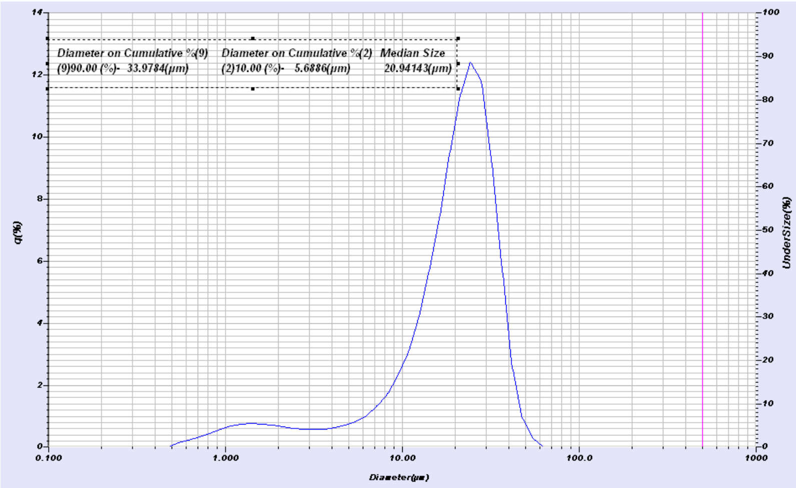
Distribution Display



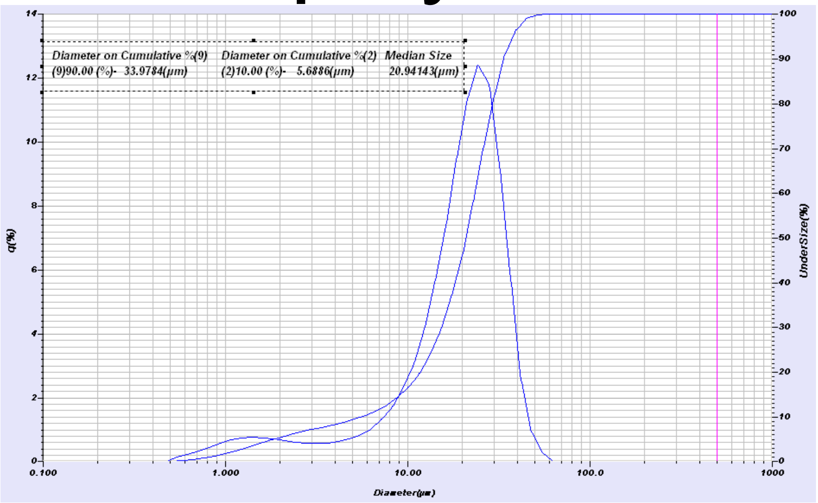
- Represented by series of segments or channels known as histogram.
- Number of channels based on design, practicality and aesthetics

© 2018 HORIBA, Ltd. All rights reserved.

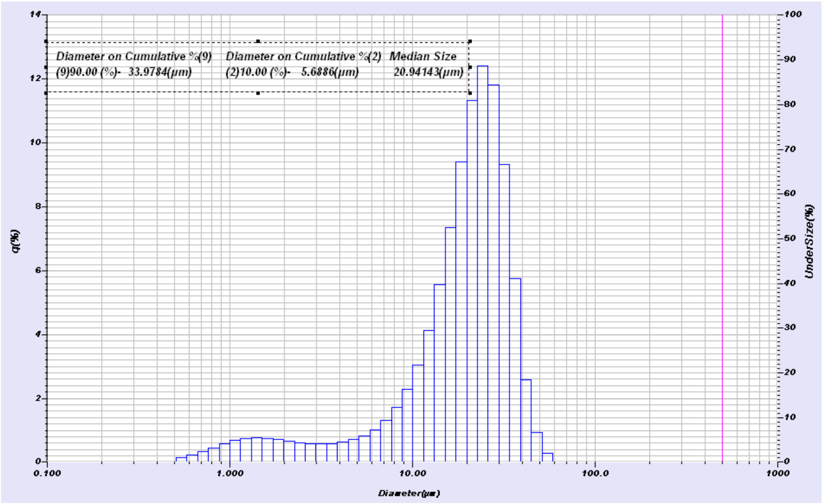
Your Analyzer’s Displays



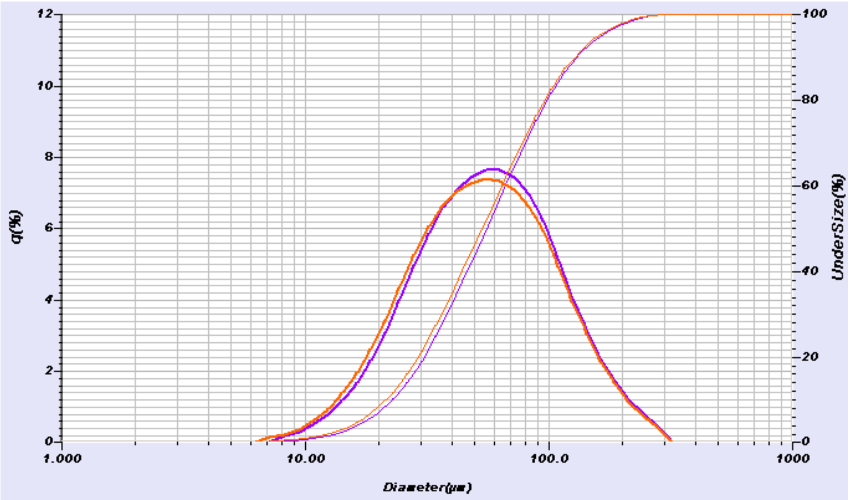
Frequency



Frequency + cumulative (undersize)



Histogram



Multiple frequency + cumulative (undersize)

© 2018 HORIBA, Ltd. All rights reserved.

Central Values

Mean

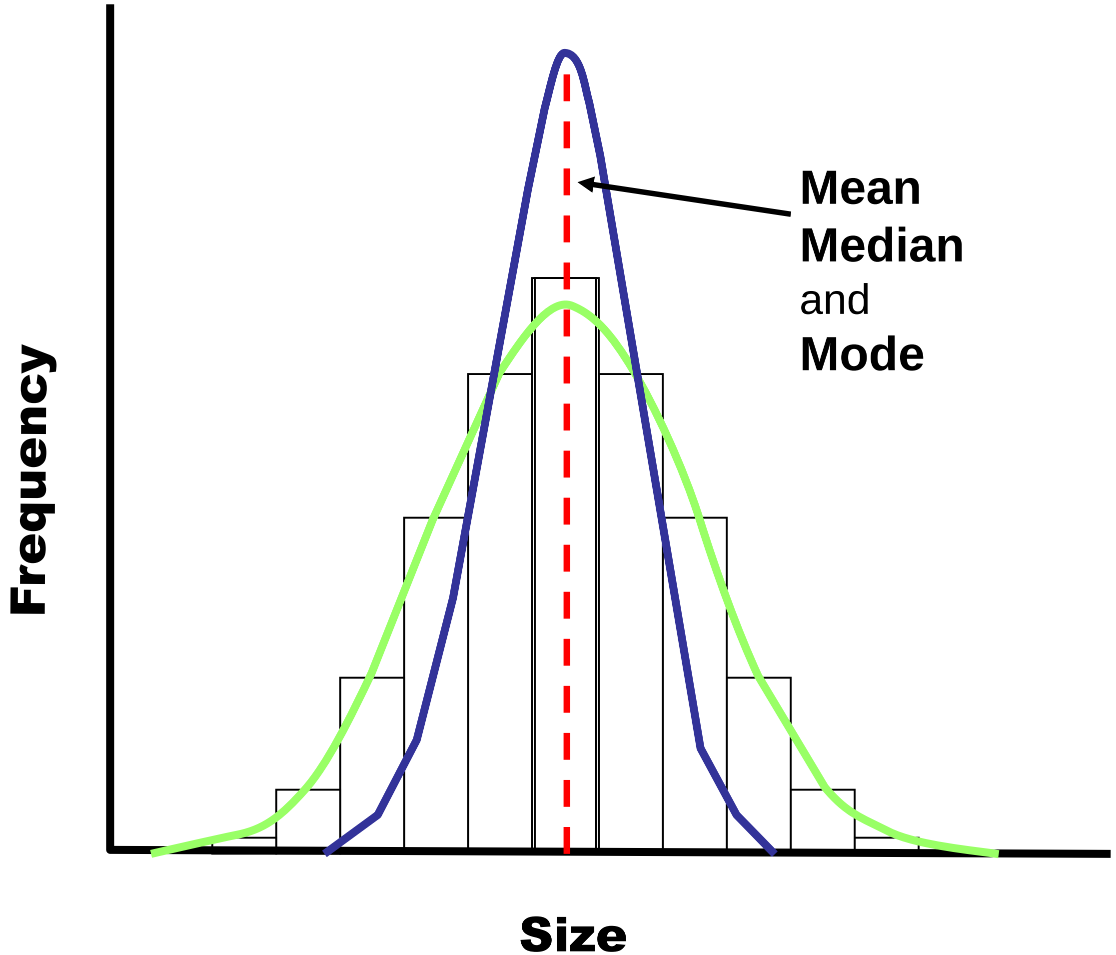
Weighted Average
Center of Gravity

Median

50% Point

Mode

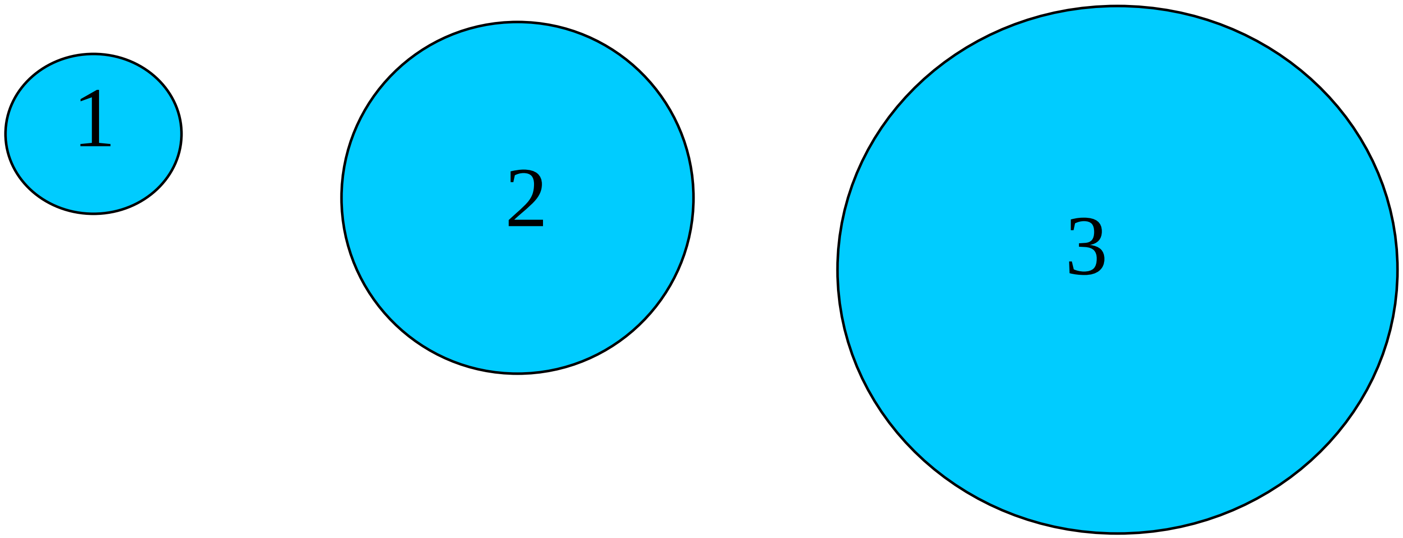
Peak of the distribution
Most common value



© 2018 HORIBA, Ltd. All rights reserved.

What does "Mean" mean?

Three spheres of diameters 1,2,3 units



What is the average size of these spheres?

Average size = (1+2+3) ÷ 3 =2.00

This is called the D[1,0] - the number mean

© 2018 HORIBA, Ltd. All rights reserved.

Many possible Mean values

$$X_{nl} = D[1,0] = \frac{1+2+3}{3} = 2.00$$

Number weighted mean Diameter (length)

Mean surface diameter

$$X_{ns} = D[2,0] = \sqrt{\frac{1+4+9}{3}} = 2.16$$

None of the answers are wrong they have just been calculated using different techniques

$$X_{nv} = D[3,0] = \sqrt[3]{\frac{1+8+27}{3}} = 2.29$$

Mean volume diameter

$$X_{sv} = D[3,2] = \frac{1+8+27}{1+2+3} = 2.57$$

Volume/surface mean,

$$X_{vm} = D[4,3] = \frac{1+16+81}{1+8+27} = 2.72$$

Volume weighted mean diameter

© 2018 HORIBA, Ltd. All rights reserved.

Moment Ratios: ISO 9276-2

For your reference

$$D[p,q] = \left[\frac{\sum n_i D_i^p}{\sum n_i D_i^q} \right]^{1/(p-q)} \qquad p \neq q$$

$$D[p,q] = \exp\left[\frac{\sum n_i D_i^p \ln D_i}{\sum n_i D_i^q} \right] \qquad p = q$$

© 2018 HORIBA, Ltd. All rights reserved.

Volume-based Mean diameter

D[4,3] which is often referred to as the Volume Mean Diameter [VMD]

$$D[4,3] = \frac{\sum D_i^4 n_i}{\sum D_i^3 n_i}$$

Monitoring the D[4,3] value in your specification will emphasize the detection of large particles

Mean Size

The frequency distribution is found using the arithmetical mean diameter, as shown in the formula below.

Mean Diameter = Σ{q(J) × X(J)} / Σ{q(J)}

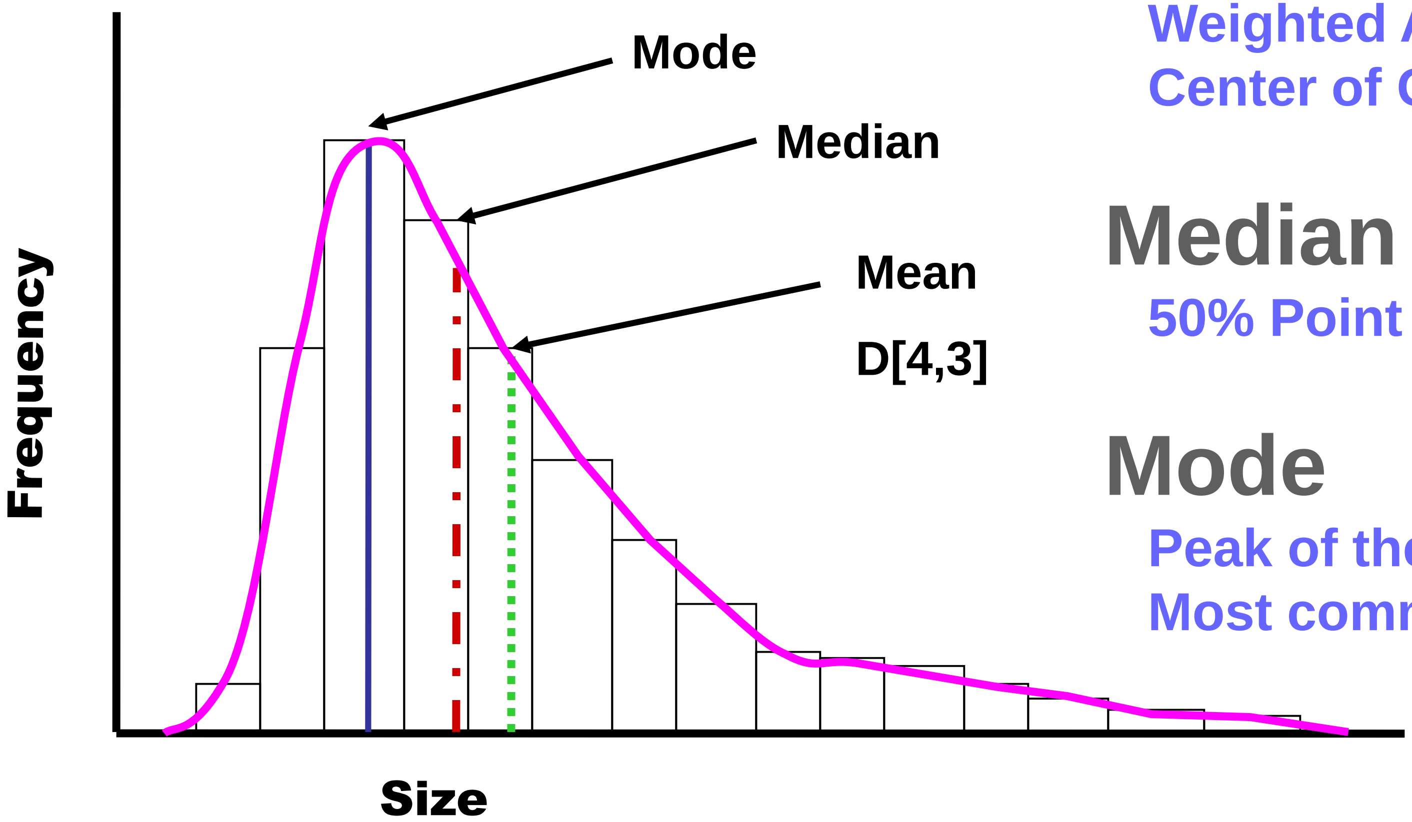
J : Particle Diameter Division Number

q(J) : Frequency Distribution Value (%)

X(J) : Jth Particle Diameter Range's Representative Diameter (μm).

© 2018 HORIBA, Ltd. All rights reserved.

Central Values revisited



Mean

Weighted Average
Center of Gravity

Median

50% Point

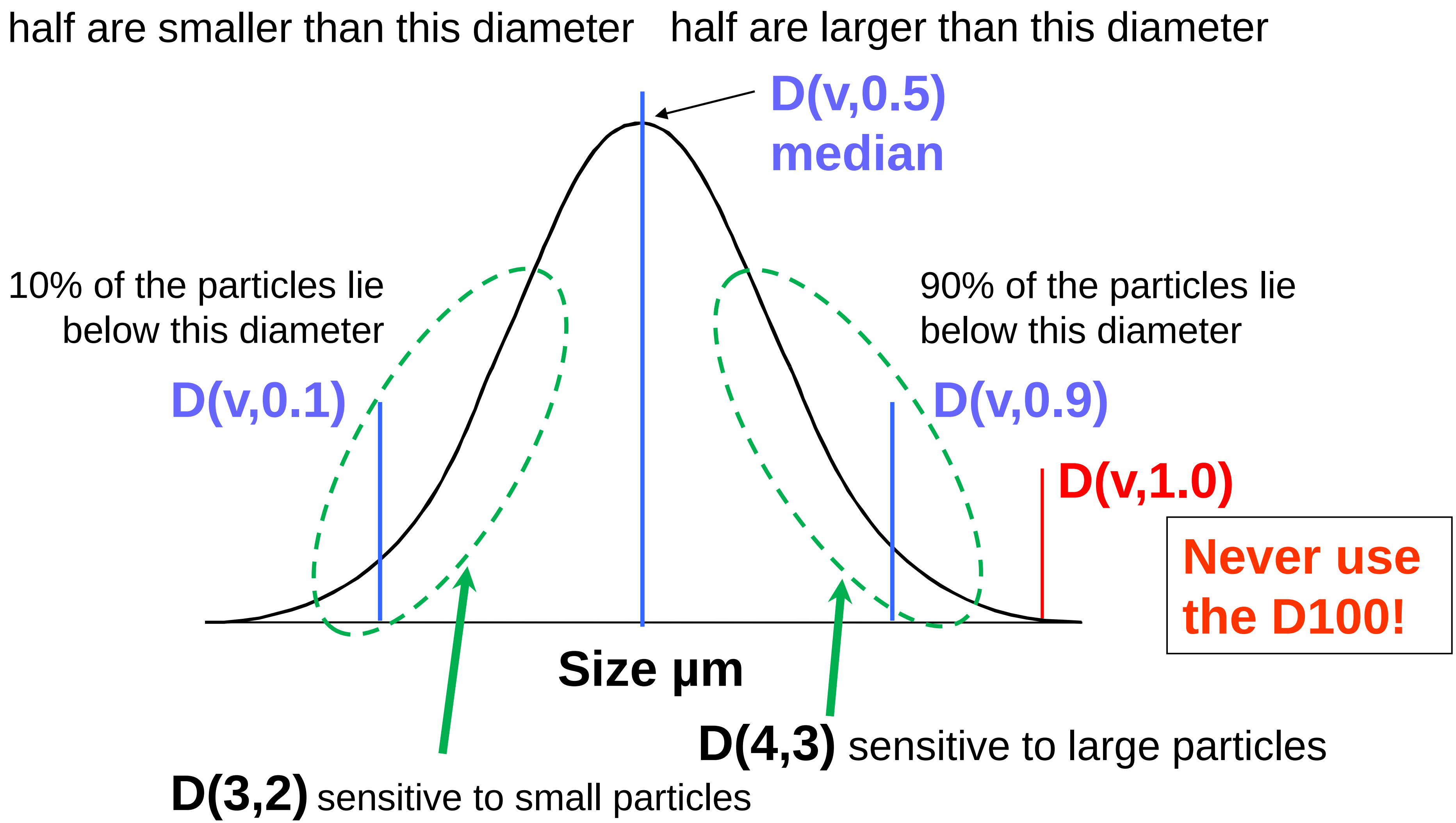
Mode

Peak of the distribution
Most common value

Remember: D[4,3] is sensitive to large particles

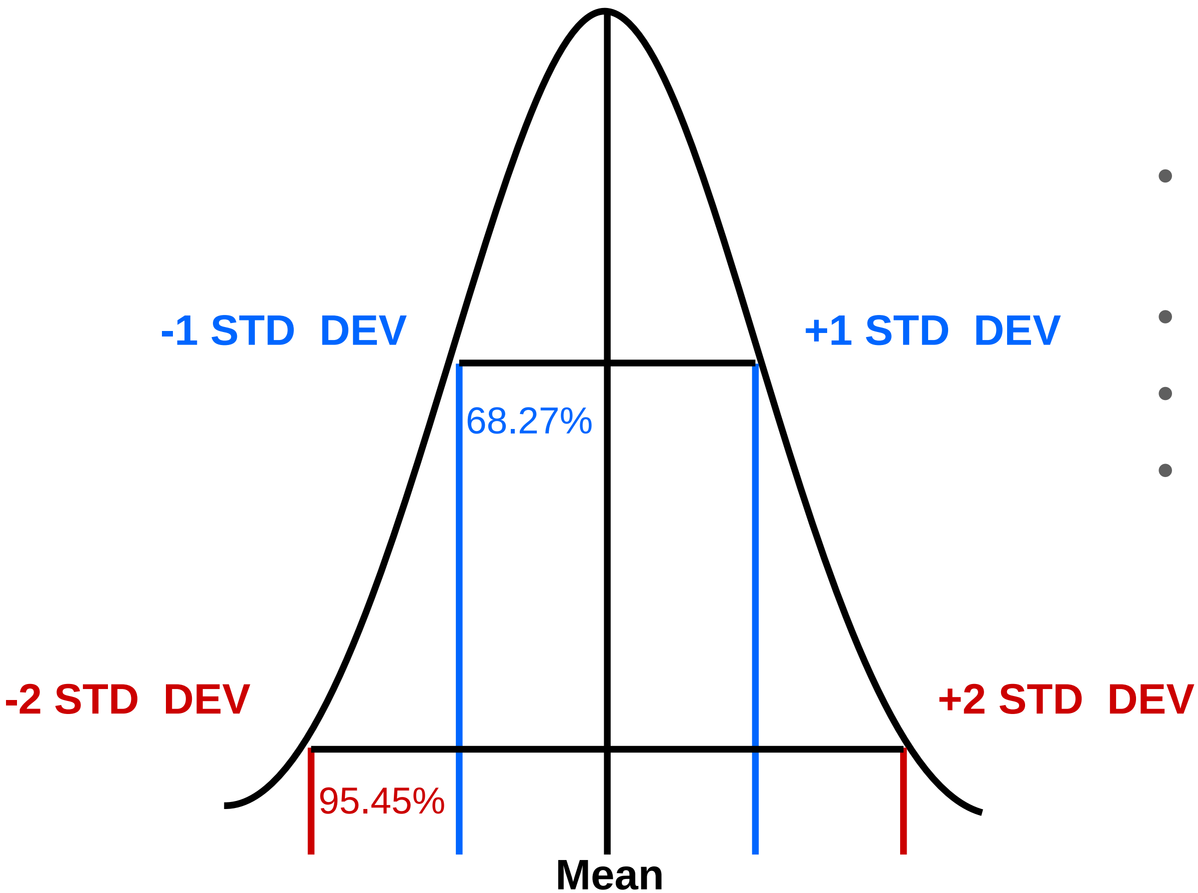
© 2018 HORIBA, Ltd. All rights reserved.

Most Common Statistics



© 2018 HORIBA, Ltd. All rights reserved.

Standard Deviation

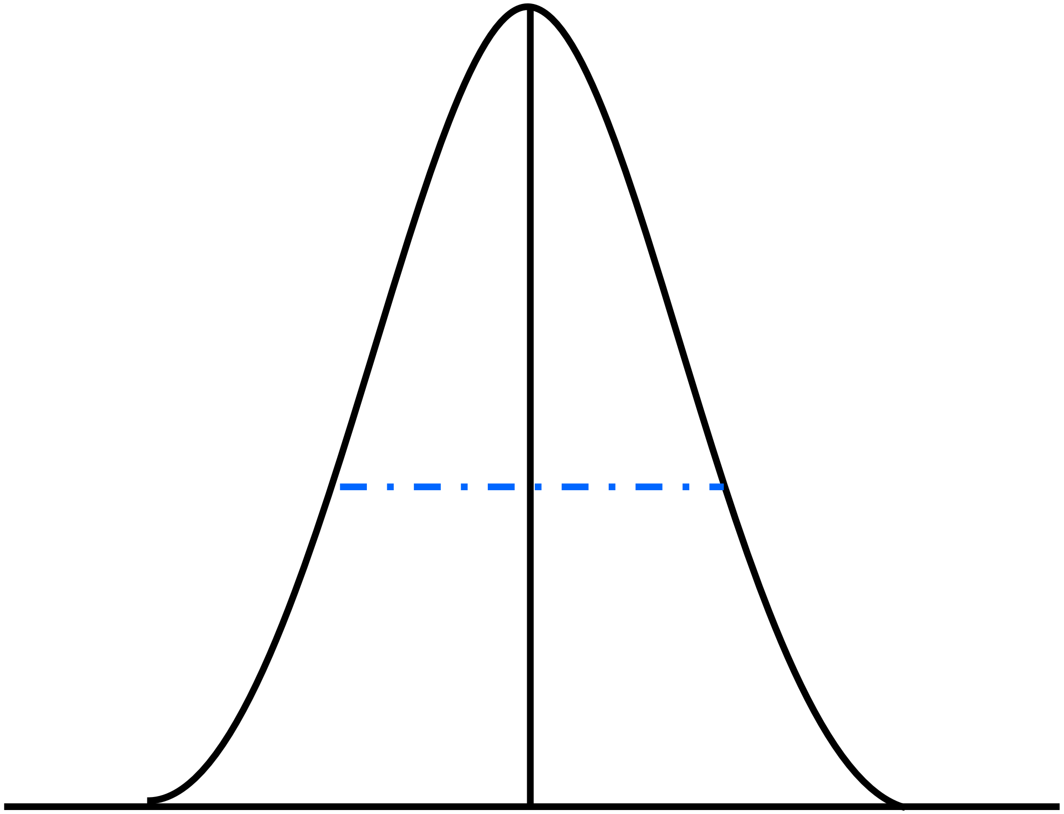


$$Y = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(x-\mu)^2}{2\sigma^2}\right]$$

- **Normal (Gaussian) Distribution Curve**
- **μ = distribution mean**
- **σ = standard deviation**
- **Exp = base of natural logarithms**

© 2018 HORIBA, Ltd. All rights reserved.

Distribution Width



- Polydispersity Index (PI, PDI)
- Span
- Geometric Std. Dev.
- Variance
- Etc…

© 2018 HORIBA, Ltd. All rights reserved.

For Your Reference

Variance

The value for the expanded distribution condition is found using the formula below.

$$\text{Variance} = \sum\left[(X(J) - \text{Mean})^2 \frac{q(J)}{100}\right]$$

J : Particle Diameter Division Number
q(J) : Distribution Graph Value(%)
X(J) : Jth Particle Diameter Range's Representative Diameter (μm)
Mean: Arithmetic Mean Diameter (μm)

Std. Dev.

Value taken from variance value's square root.

Coefficient of Variation (CV)

This result of dividing the arithmetic standard deviation (Std. Dev.) by the mean diameter.

Mode Size

Frequency distribution value's largest values that become particle diameters of the frequency distribution graph's peak.

Span

Value that becomes the criteria for widening the distribution, as shown below.
Not displayed if both of the diameter on cumulative % are not set.

$$\text{Span Value} = \frac{(\text{Diameter on cumulative \% A - Diameter on cumulative \% B})}{\text{Median diameter}}$$

Diameter on cumulative % A: the first value set in the display conditions.
Diameter on cumulative % B: the second value set in the display conditions.

Note: Span typically = $(d_{90} – d_{10})/ d_{50}$

© 2018 HORIBA, Ltd. All rights reserved.

For Your Reference

Geometric Mean Size

The frequency distribution is found using the geometric mean value, as shown in the formula below.

$$\text{Geometric Mean Diameter} = 10^{\frac{\sum(\log X(J) \times q(J))}{\sum q(J)}}$$

J : Particle Diameter Division Number
q(J) : Frequency Distribution Value (%)
X(J) : Jth Particle Diameter Range's Representative Diameter (μm)

Geometric Variance

The value for the expanded distribution condition is found using the formula below.

$$\text{Geometric Variance} = 10^{\sum(\log X(J) - \log(\text{Mean}))^2 \cdot \frac{q(J)}{100}}$$

J : Particle Diameter Division Number
q(J) : Frequency Distribution Value (%)
X(J) : Jth Particle Diameter Range's Representative Diameter (μm)
Mean : Geometric Mean Diameter (μm)

Geometric Standard Deviation

$$\text{Geometric Distribution Deviation} = 10^{\sqrt{\sum(\log X(J) - \log(\text{Mean}))^2 \cdot \frac{q(J)}{100}}}$$

J : Particle Diameter Division Number
q(J) : Frequency Distribution Value (%)
X(J) : Jth Particle Diameter Range's Representative Diameter (μm)
Mean : Geometric Mean Diameter (μm)

© 2018 HORIBA, Ltd. All rights reserved.

For Your Reference

Error Calculations in LA-960 only

Chi Square

Indicates the degree of similarity between the refractive index used to produce the particle size distribution calculation result and the actual scattering data. The closer to "0", the greater the similarity. Becomes the selection's criterion when the refractive index is not known for the sample being measured. Chi Square(χ2) is found using the following formula.

$$\chi^2 = \sum\left\{\frac{1}{\sigma_i^{\,2}}[y_i - y(x_i)]^2\right\}$$

y_i :Actual scattering measurement data

$y(x_i)$:Scattering data found using refractive index file data and displayed particle size distributions

σ_i :Scattering data standard deviation

R Parameter

Indicates the degree of similarity between the refractive index used to produce the particle size distribution calculation result and the actual scattering data. The closer to "0", the greater the similarity.

Becomes the selection's criterion when the refractive index is not known for the sample being measured.

The Residual R Parameter is found using the following formula.

$$R = \frac{1}{N}\sum_{i=1}^{N}\left\{\frac{1}{y_{(x_i)}}\left|y_i - y(x_i)\right|\right\}$$

y_i :i-th detector channel's actual scattering measurement data

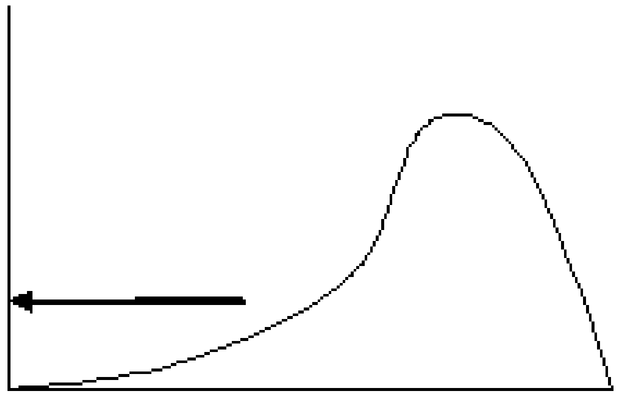
$y(x_i)$: Scattering data calculated by calculating backwards from the refractive index data and the displayed particle size distribution.

N : Number of light detector channels

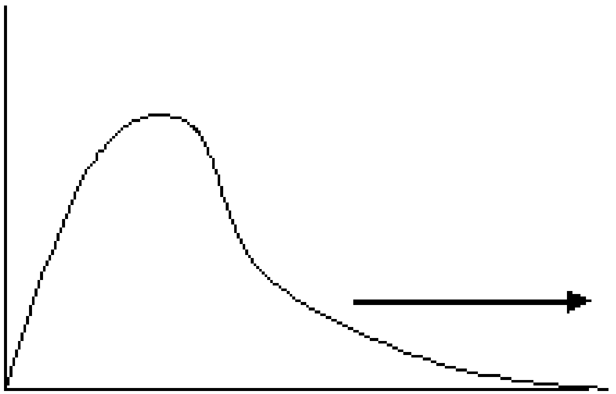
© 2018 HORIBA, Ltd. All rights reserved.

Skewness

1. **positive skew**: The right tail is longer; the *mass* of the distribution is concentrated on the left of the figure. The distribution is said to be *right-skewed*.
2. **negative skew**: The left tail is longer; the mass of the distribution is concentrated on the right of the figure. The distribution is said to be *left-skewed*.



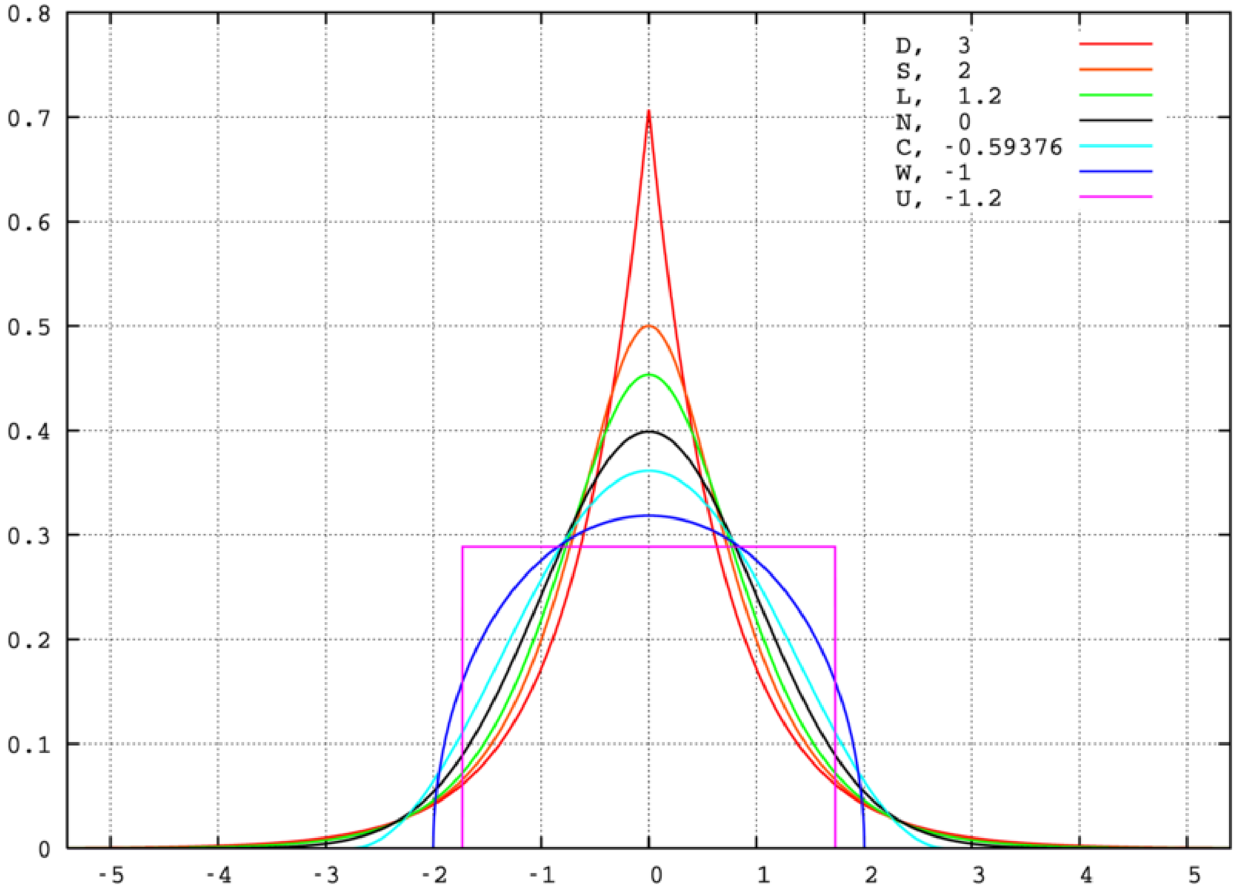
Negative Skew
Elongated tail at the **left**
More data in the left tail than would be expected in a normal distribution



Positive Skew
Elongated tail at the **right**
More data in the right tail than would be expected in a normal distribution

© 2018 HORIBA, Ltd. All rights reserved.

Kurtosis (Peakedness)



From highest to lowest peak:
red, kurtosis 3
orange, kurtosis 2
green, kurtosis 1.2
black, kurtosis 0,
cyan, kurtosis −0.593762…
blue, kurtosis −1
magenta, kurtosis −1.2

© 2018 HORIBA, Ltd. All rights reserved.

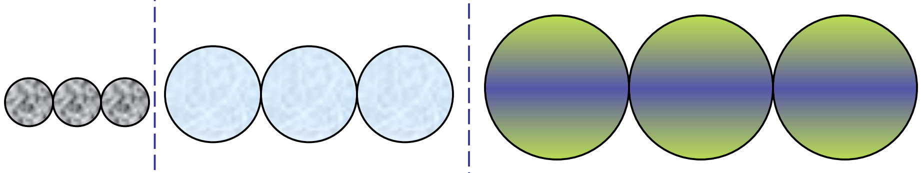
Number vs. Volume Distributions

r = 1 µm
v = 4

r =2 µm
= 32

r = 3 µm
= 108

$V = \frac{4}{3} \pi r^3$

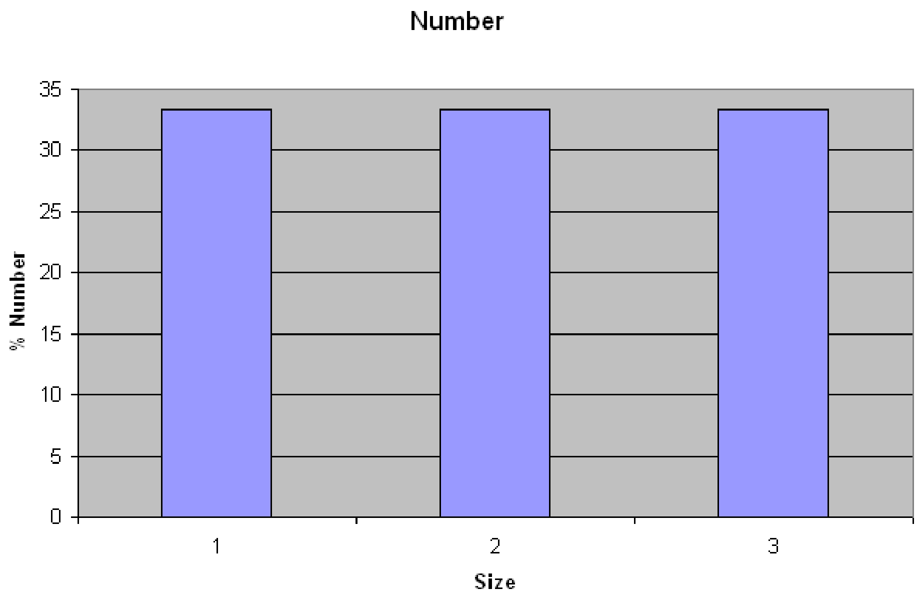


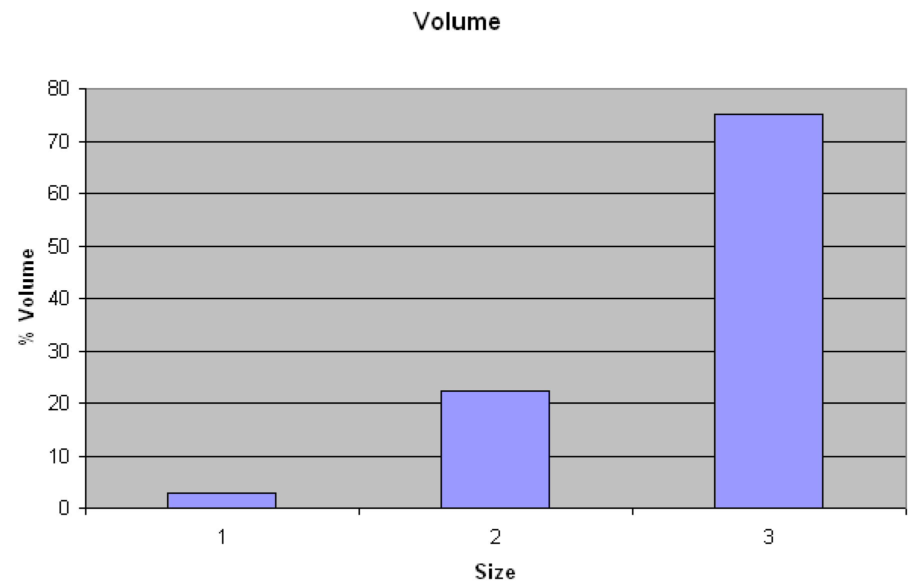
V*3 = 12
12/432=2.8%

96
96/432=22.2%

324
324/432=75%

Total = 12+96+324 = 432



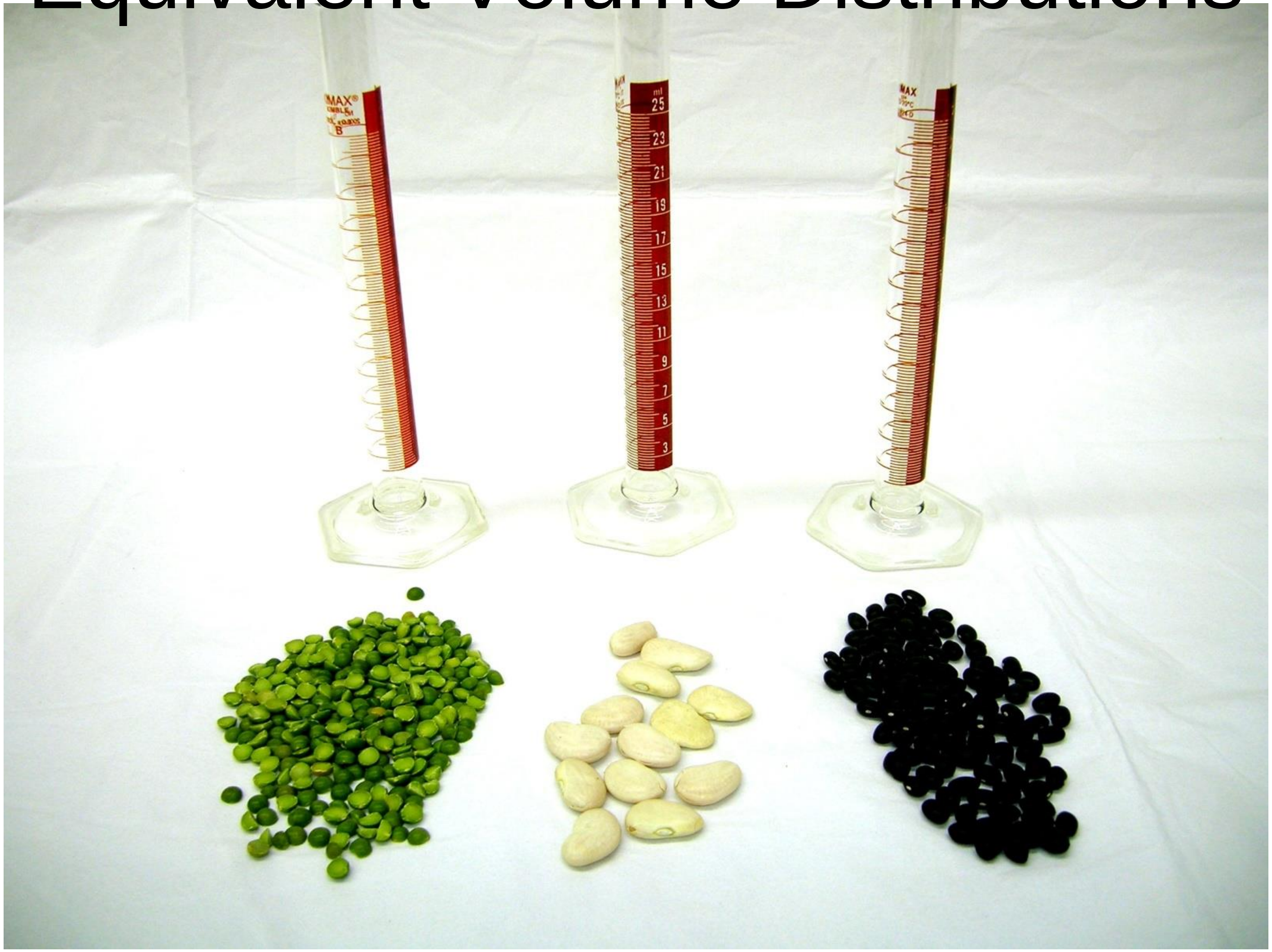


© 2018 HORIBA, Ltd. All rights reserved.

Beans!

© 2018 HORIBA, Ltd. All rights reserved.

Equivalent Volume Distributions



© 2018 HORIBA, Ltd. All rights reserved.

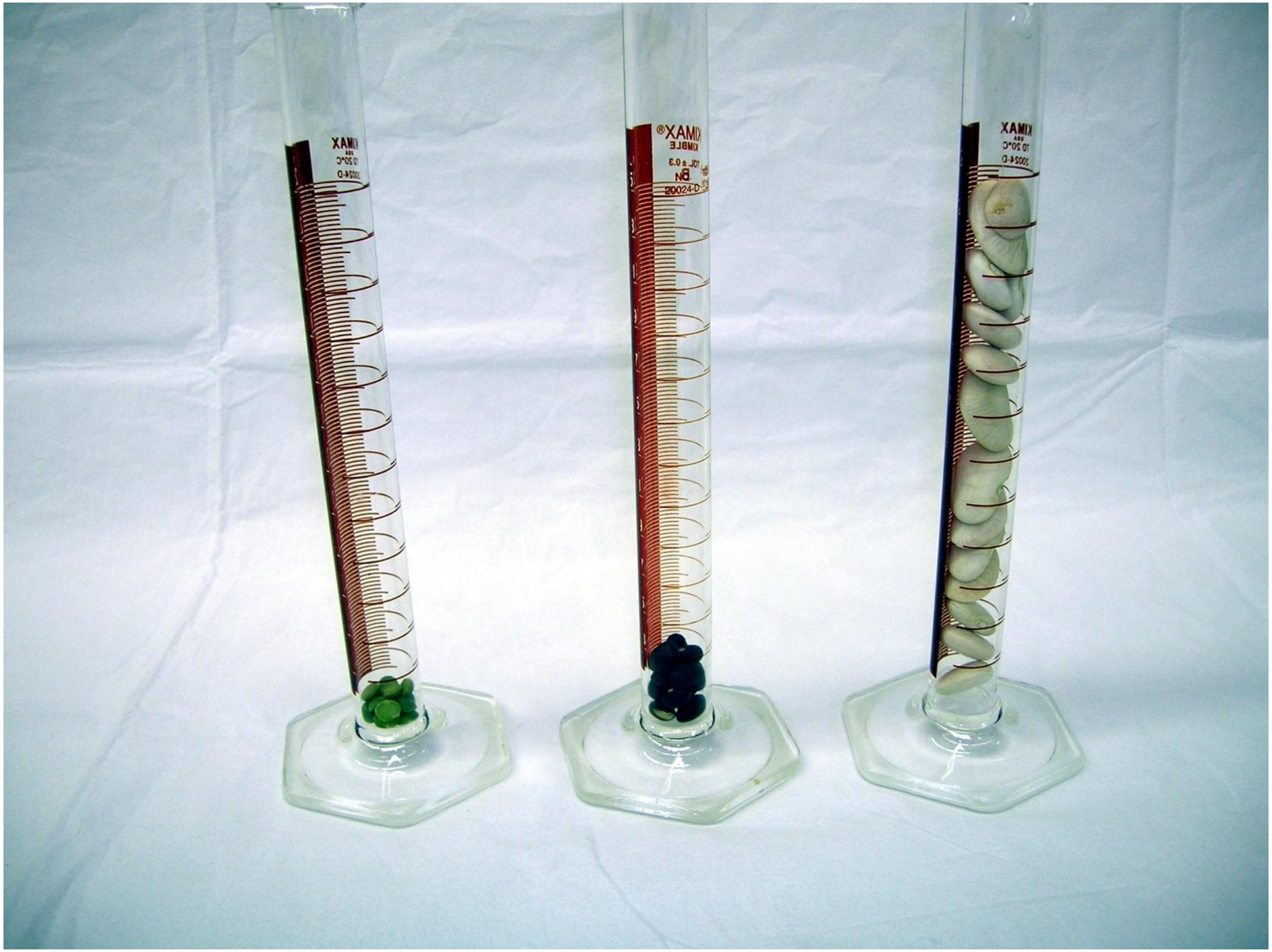
Equivalent Volume Distributions

© 2018 HORIBA, Ltd. All rights reserved.

Equivalent Number Distributions

© 2018 HORIBA, Ltd. All rights reserved.

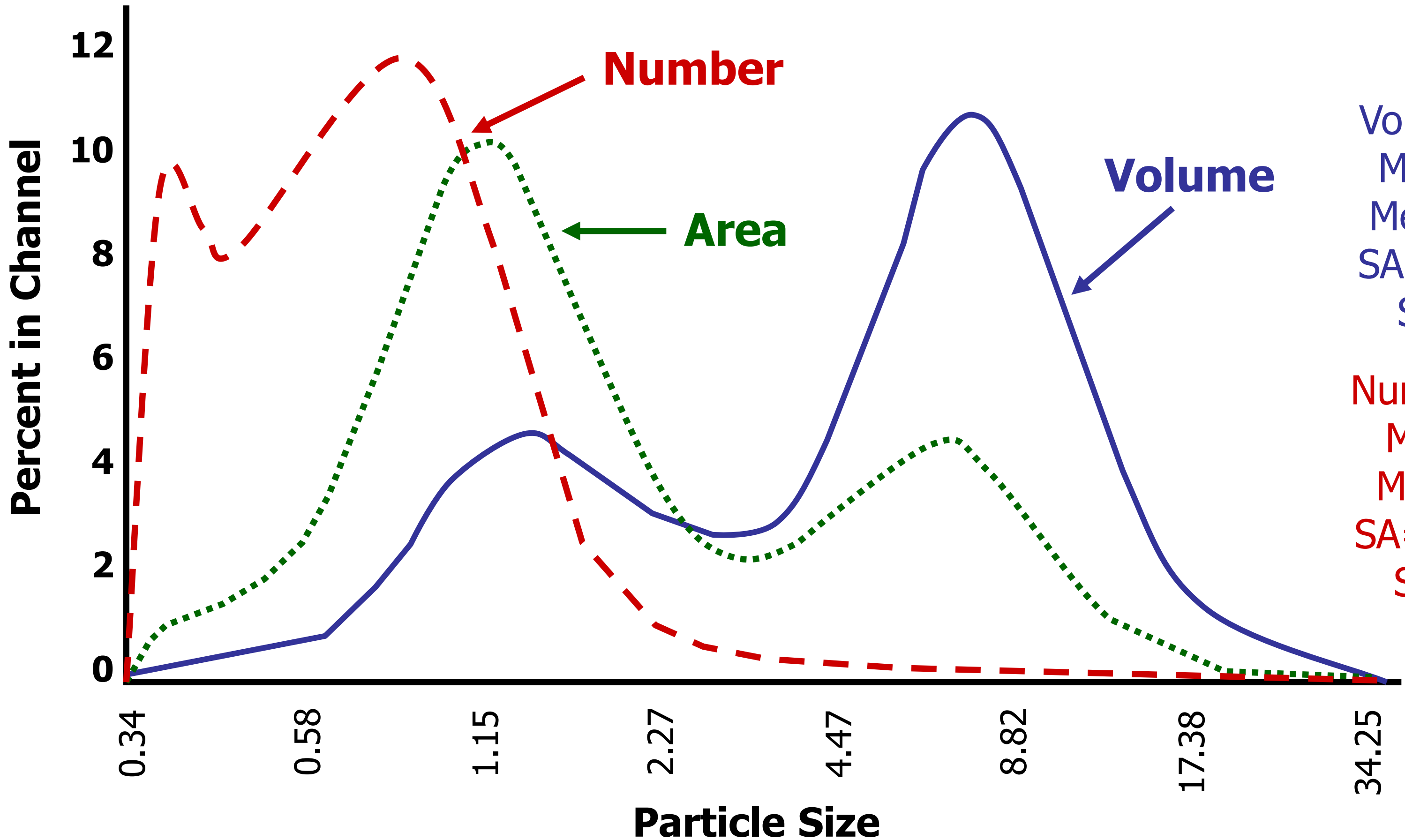
Equivalent Number Distributions



© 2018 HORIBA, Ltd. All rights reserved.

Comparing Distribution Bases

- Same material shown as volume, number and area distribution



Volume Distribution
Mean = 12.65µm
Median=11.58 µm
SA=13467 cm^2/cm^3
Std Dev.=8.29

Number Distribution
Mean = 0.38µm
Median=0.30 µm
SA=13467 cm^2/cm^3
Std Dev.=0.40

© 2018 HORIBA, Ltd. All rights reserved.

Statistical Issues with Distributions

- L Neumann, E T White, T Howes (Univ. Queensland) “What does a mean size mean?” 2003 AIChE presentation at Session 39 Characterization of Engineered particles November 16 - 21 San Francisco

Other references:

- L Neumann, T Howes, E T White (2003) Breakage can cause mean size to increase Dev. Chem. Eng. Mineral Proc. J.
- White E T, Lawrence J. (1970), Variation of volume surface mean for growing particles, Powder Technology,4, 104 - 107

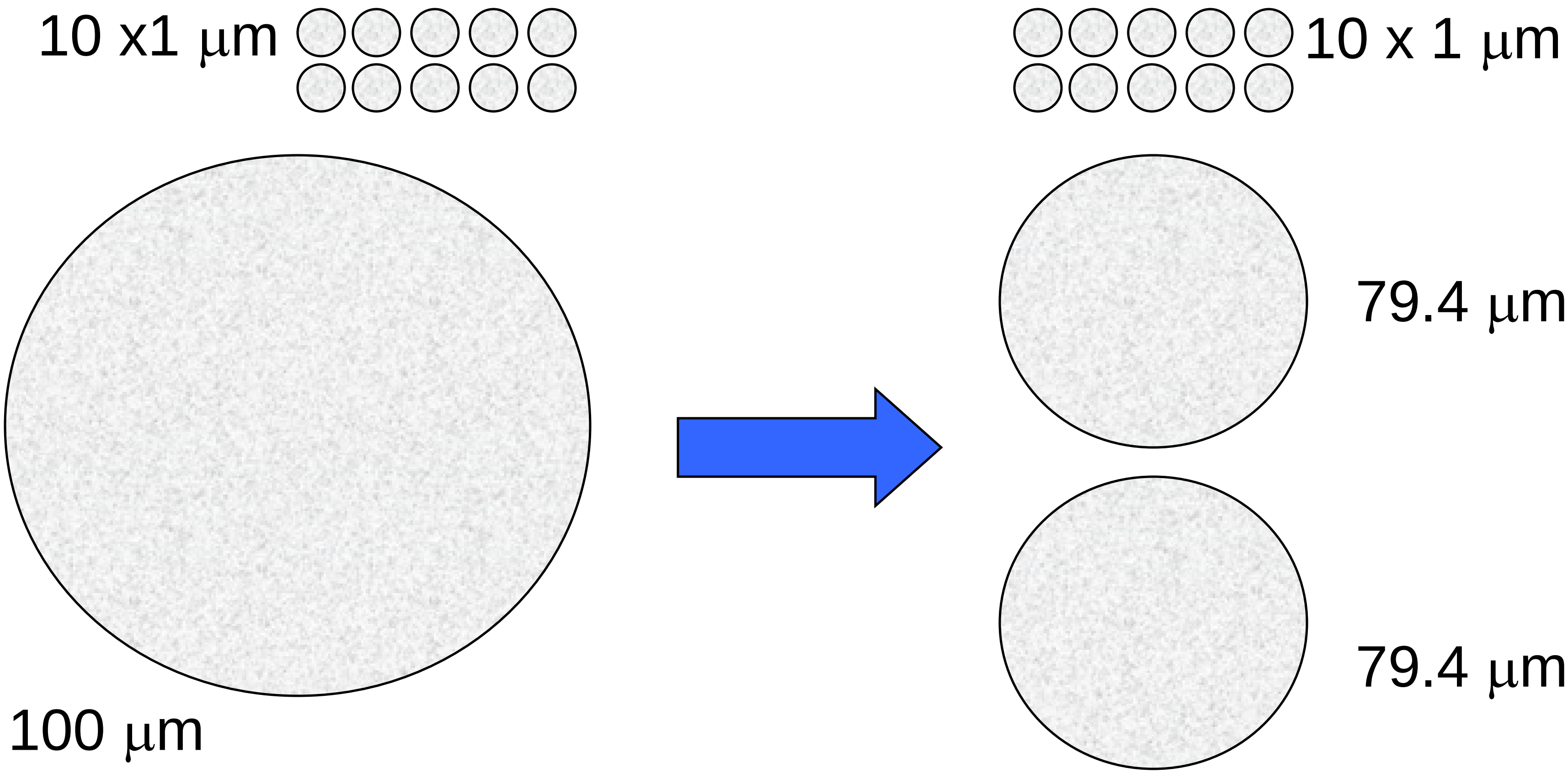
© 2018 HORIBA, Ltd. All rights reserved.

Does the Mean Match the Process?

- Particle size measurements often made to monitor a process
  - Size reduction (milling)
  - Size growth (agglomeration)
- Does the measured/calculated mean diameter describe the change due to the process?
- It depends on which mean used…

© 2018 HORIBA, Ltd. All rights reserved.

Size Reduction Scenario



100 μm
breaks into two smaller particles

© 2018 HORIBA, Ltd. All rights reserved.

Size Reduction: Number Mean

Ten particles of size 1; one of size 100 units

Number mean = D[1, 0] = (10*1 + 1*100)/11 = 10 units

..

Largest particle (100) breaks into two of 79.37

(conserves volume/mass: 2 @ 79.37^3 = 1 @ 100^3)

Have broken one

What happens to the number mean?

Mean = (10*1+2*79.37)/12 = 14.06 units

Surprise, surprise a 40.6% increase!

© 2018 HORIBA, Ltd. All rights reserved.

Size Reduction: Volume Mean

Ten particles of size 1; one of size 100 units

Volume Moment Mean

$D[4, 3] = (10*1^4 + 1*100^4)/(10*1^3 + 1*100^3) \sim \underline{100}$ units

..

Largest particle (100) breaks into two of 79.37

(conserves volume/mass: $2 @ 79.37^3 = 1 @ 100^3$)

Have broken one

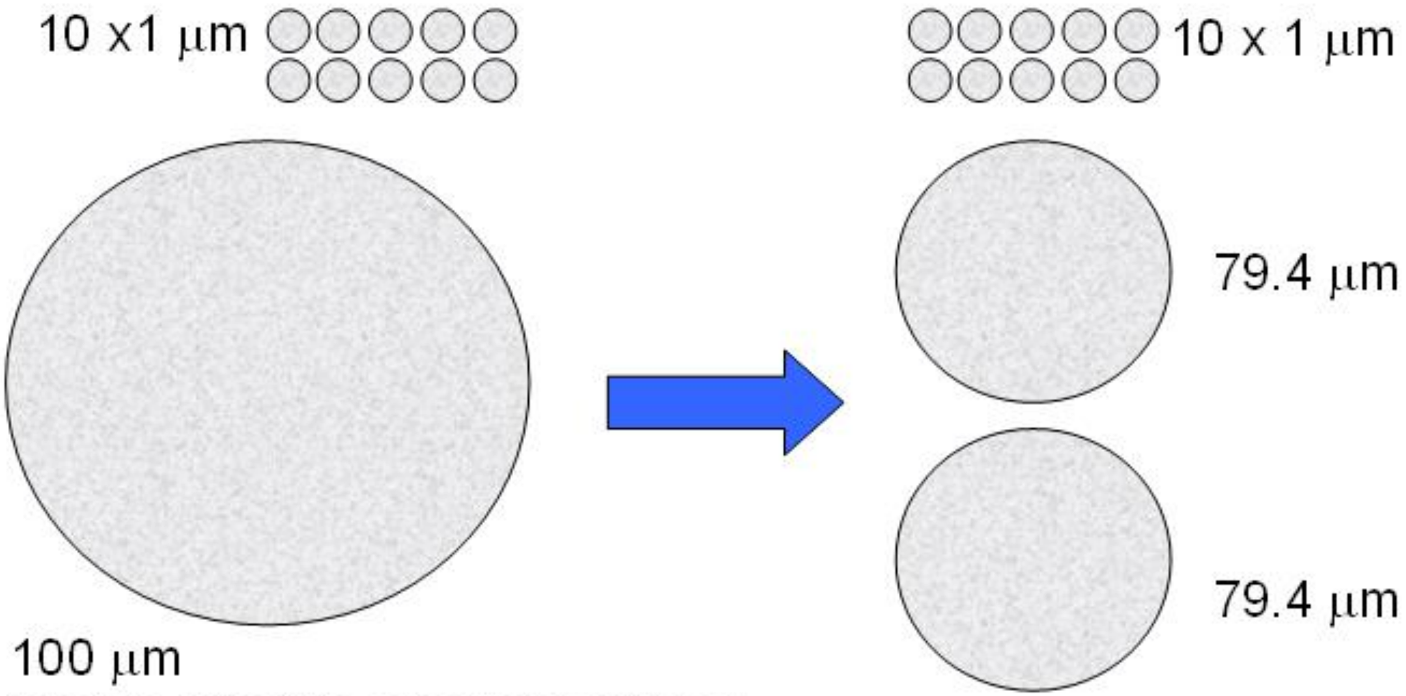
What happens to the D[4, 3]?

New $D[4, 3] = (10*1^4+2*79.37^4)/(10*1^3 +2*79.37^3) \sim \underline{79.37}$ units

This shows the expected behavior

© 2018 HORIBA, Ltd. All rights reserved.

Can You See the Problem?

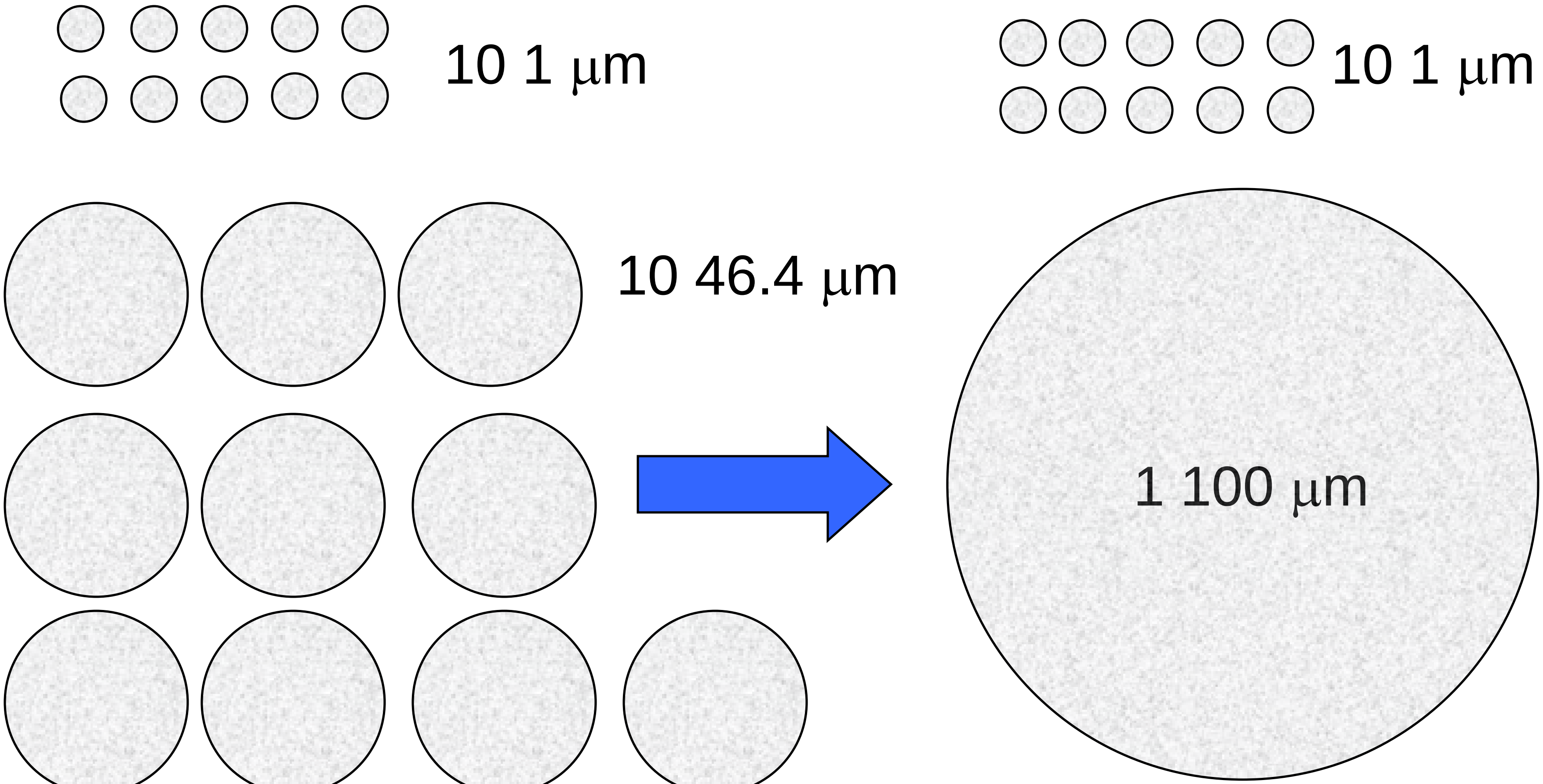


100 µm
breaks into two smaller particles

Number mean = 10	Number mean = 14 ↑
Volume mean = 100	Volume mean = 79 ↓

© 2018 HORIBA, Ltd. All rights reserved.

Size Growth Scenario



Ten 46.4 μm particles agglomerate into one 100 μm particle

© 2018 HORIBA, Ltd. All rights reserved.

Growth: Number Mean

Ten particles of size 1; ten of size 46.42

D[1, 0] = (10*1 + 10*46.42)/20 = 23.71 units

Ten of 46.42 agglomerate into one of 100

(conserves volume/mass: 10 @ 46.42^3 = 1 @ 100^3)

Have agglomerated half; does mean increase?

Mean = (10*1+1*100)/11 = 10 units

Over a 50% decrease!

© 2018 HORIBA, Ltd. All rights reserved.

Growth: Volume Mean

Ten particles of size 1; ten of size 46.42

$D[4, 3] = (10*1^4 + 10*46.42^4)/(10*1^3 + 10*46.42^3)$

~ 46.4 units

(Note again the volume moment mean is dominated by the large particles)

Ten of 46.42 agglomerate into one of 100

(conserves volume/mass: $10 @ 46.42^3 = 1 @ 100^3$)

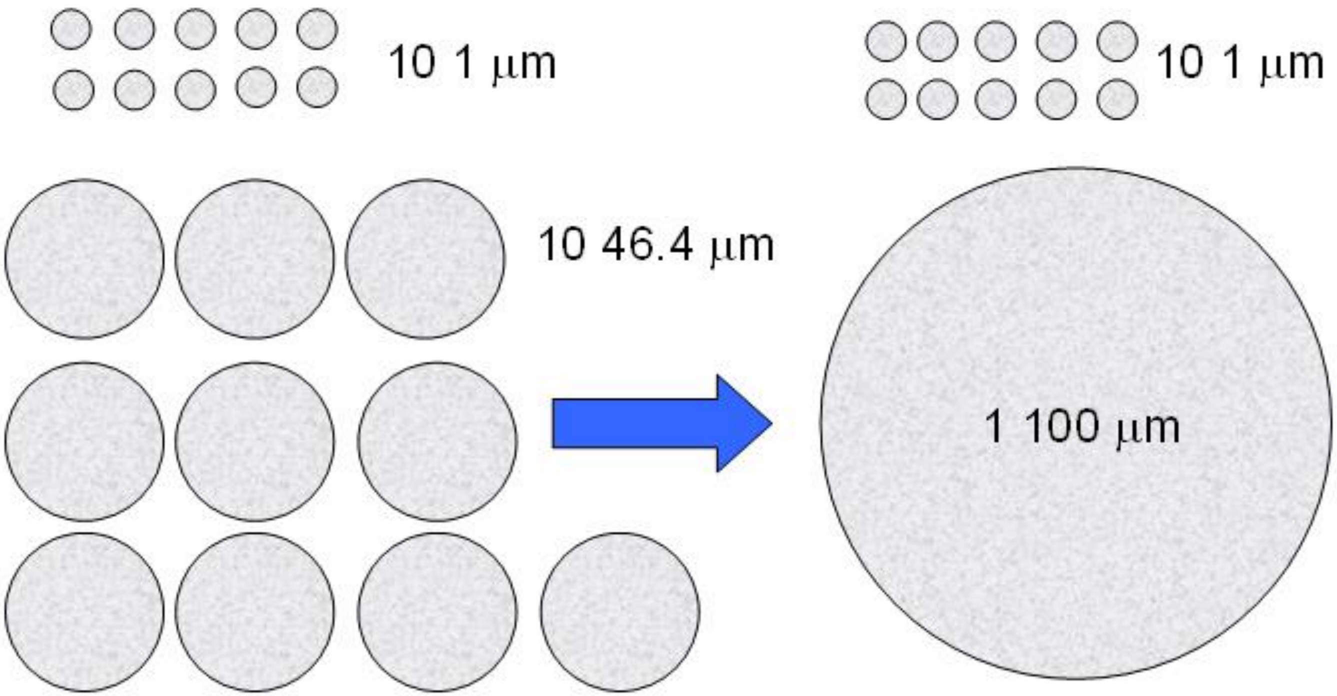
Have agglomerated half; does mean increase?

$D[4, 3] = (10*1^4+1*100^4)/10*1^3 + 1*100^3$ ~ 100 units

This shows the expected behavior

© 2018 HORIBA, Ltd. All rights reserved.

Can You See the Problem?



Ten 46.4 µm particles agglomerate into one 100 µm particle

Number mean = 24	Number mean = 10 ↓
Volume mean = 46	Volume mean = 100 ↑

© 2018 HORIBA, Ltd. All rights reserved.

Practical Implications

- Not just a "party trick" topic!

  "Do you know you can break particles and the mean will increase?"

- Serious. "Did an experiment. I thought I broke particles but the mean has increased"

  (REAL experience)

- Should be aware it can happen!

- Analyse whole size distribution, not mean alone.

© 2018 HORIBA, Ltd. All rights reserved.

METHODS OF ANALYSIS

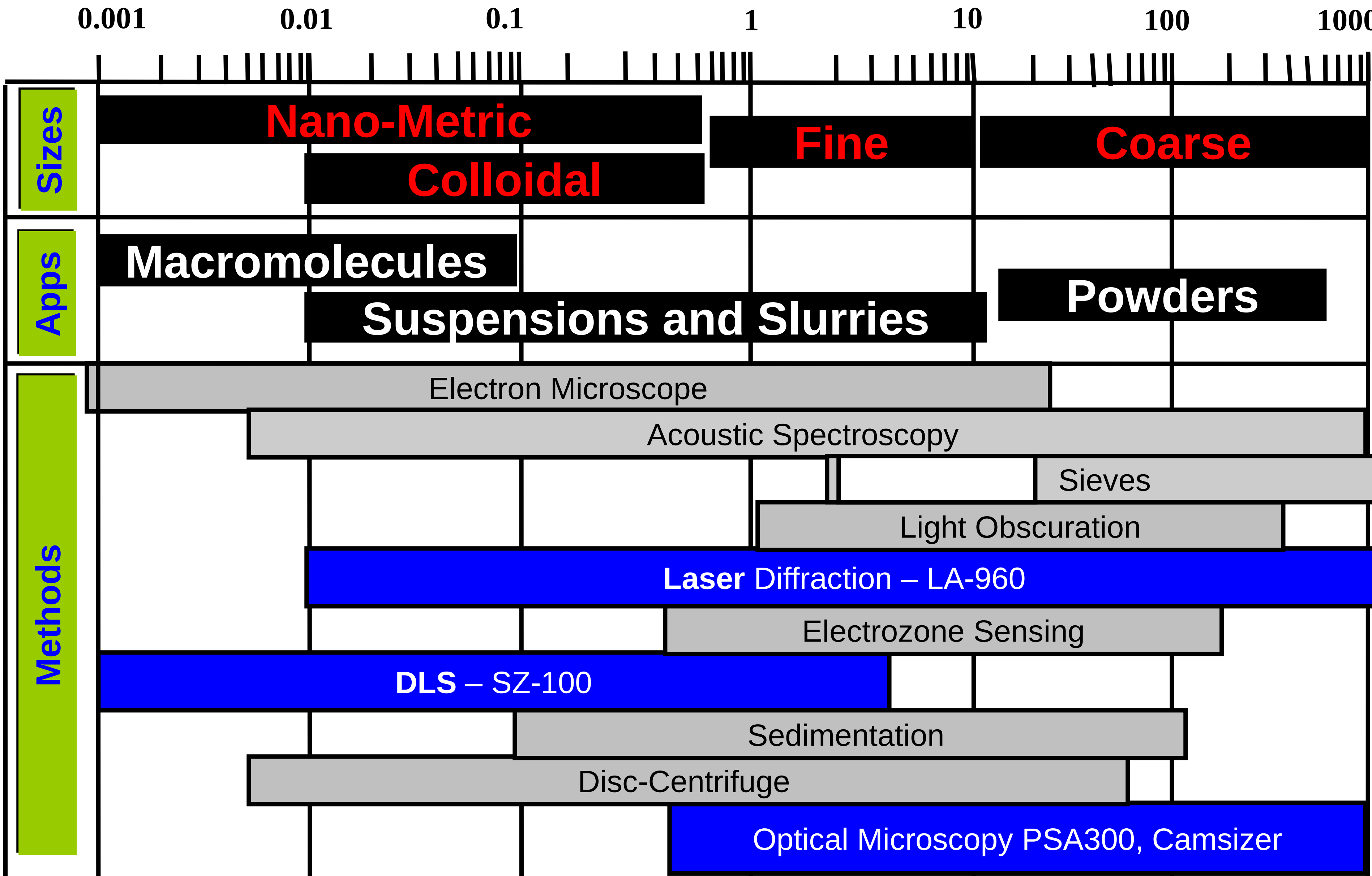
PARTICLE MEASUREMENT METHODS

PSA Method is Important

- Why should one consider various methods of particle size analysis?
  - Material suppliers and users employ many different types of instruments
  - Use a different technique = get a different answer
  - It is important to understand how analysis methods differ in order to know how to compare data

© 2018 HORIBA, Ltd. All rights reserved.

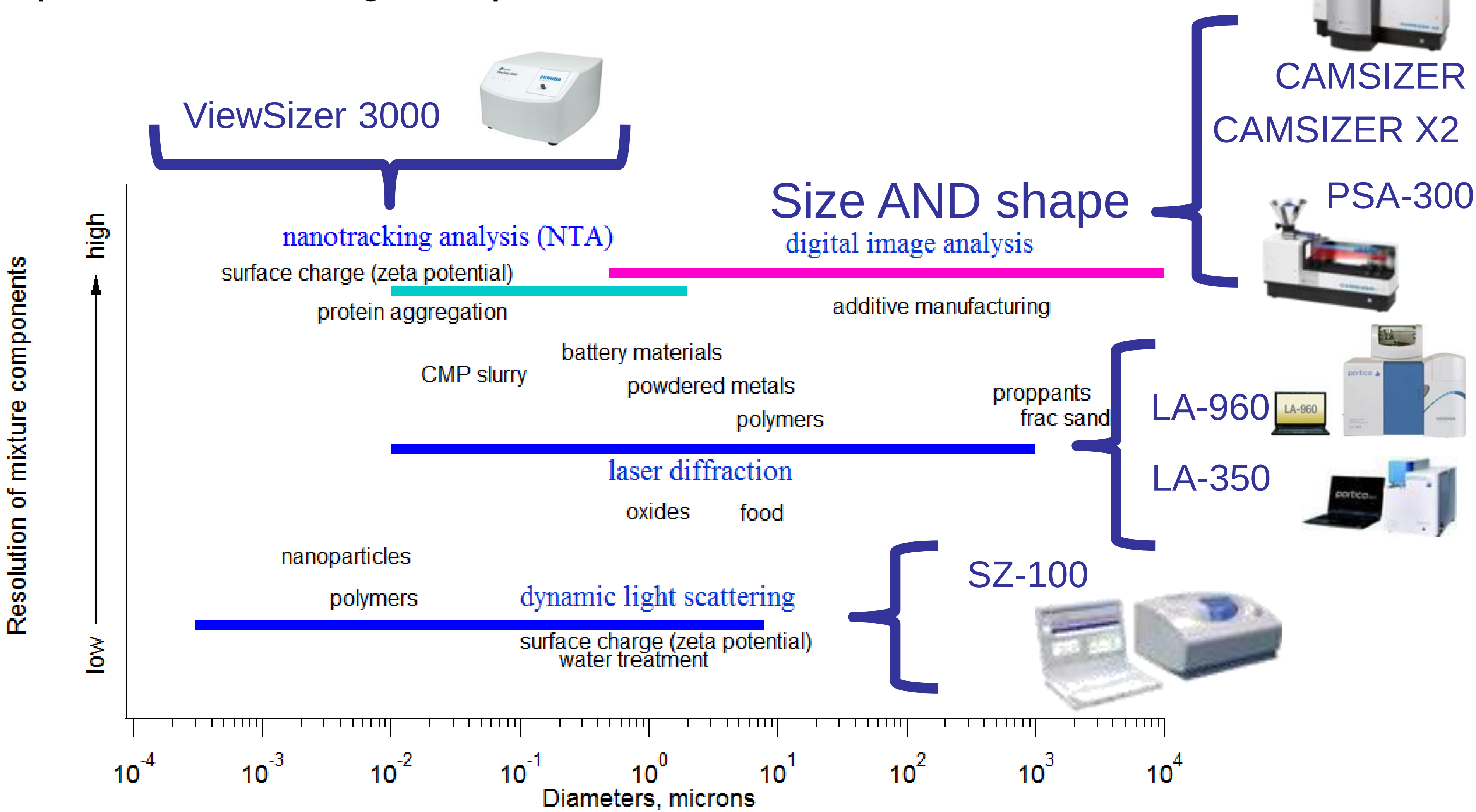
Size Range by Technique (µm)



© 2018 HORIBA, Ltd. All rights reserved.

Which Analyzer?

Size, desired resolution, and budget determine technology and product. For a given problem the choice is often clear.

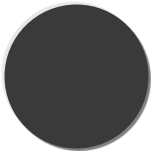


© 2018 HORIBA, Ltd. All rights reserved.

What Size is Measured?

Laser Diffraction

Equivalent Spherical Diameter



Dynamic Light Scattering

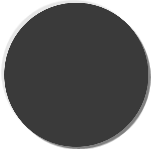
Hydrodynamic Radius

Image Analysis

Lengths, Widths, Equivalent Spherical

Acoustic Spectroscopy

Equivalent Spherical Diameter



© 2018 HORIBA, Ltd. All rights reserved.

Particle Shape Definitions

Acicular:	**Needle-shaped, rigid**
Angular:	**Edgy, hard angles**
Fibrous:	**Thread-like, non-rigid**
Granular/Blocky:	**Irregular-shaped, low aspect-ratio**
Spherical:	**Regular-shaped, unity aspect ratio**
Aspect ratio:	**Breadth / length OR Length / breadth**
Sphericity:	**How spherical is the particle?**
Roundness:	**How round is the particle?**

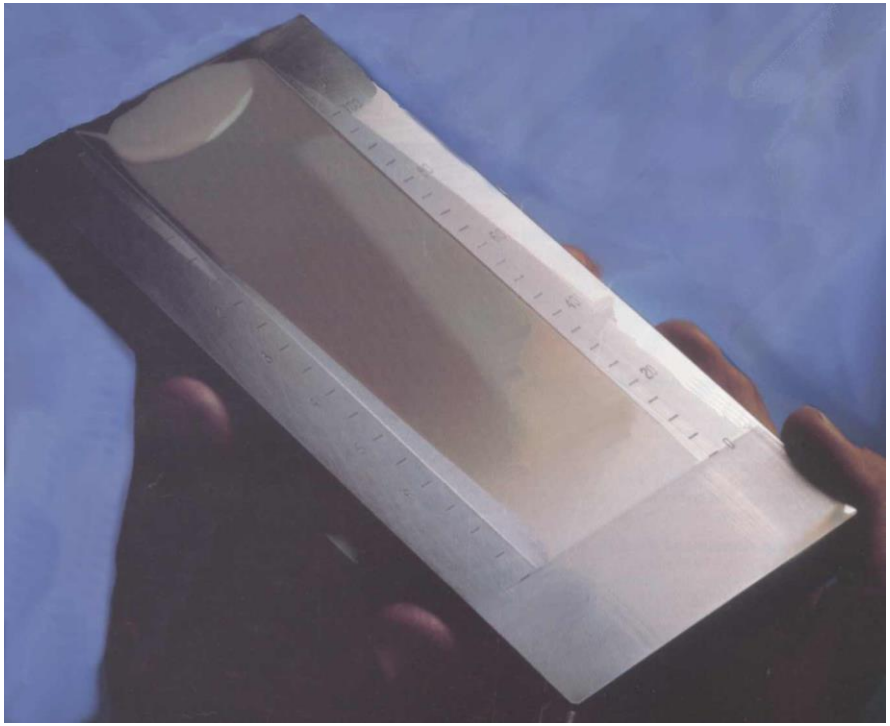
© 2018 HORIBA, Ltd. All rights reserved.

Poll!

What are the shapes of your particles?

Hegman Gauge

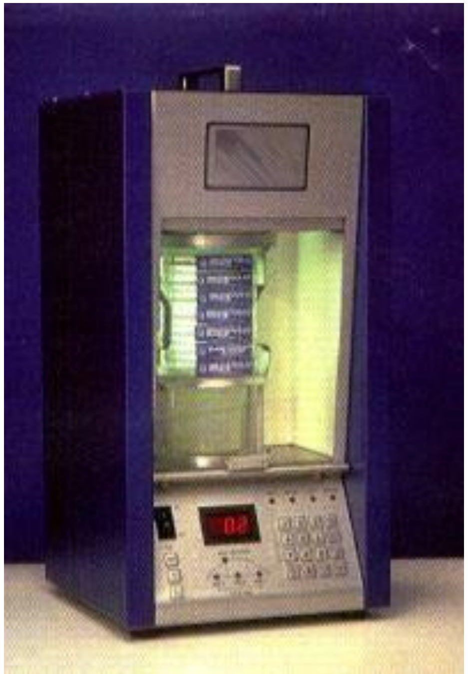
- Used in paint and coatings industry
  - Device has tapered center channel
  - Slurry is placed in channel, then straight edge is drawn across it
  - “Hegman Number” is where particles disturb smooth surface of slurry
  - Information from largest particles only – no distribution



© 2018 HORIBA, Ltd. All rights reserved.

Sieves

- Weigh % sample caught on known screen sizes
- Solid particles 30 μm – 30 mm (and larger)



Advantages:
- Low equipment cost
- Direct measurement method
- No practical upper limit

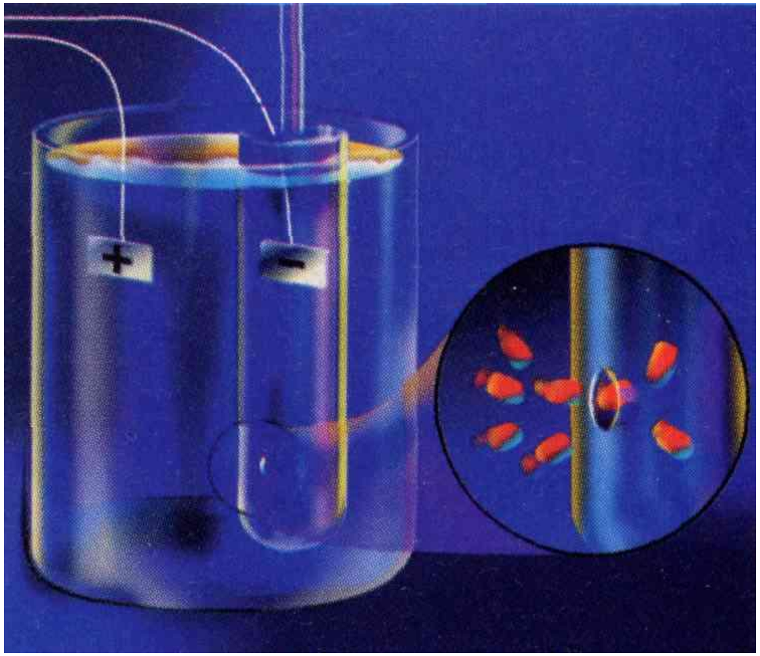
Disadvantages:
- Limited lower range
- Time Consuming
- High Labor Cost
- Need Large Sample

Available through www.retsch.com

© 2018 HORIBA, Ltd. All rights reserved.

Electrical Sensing Zone

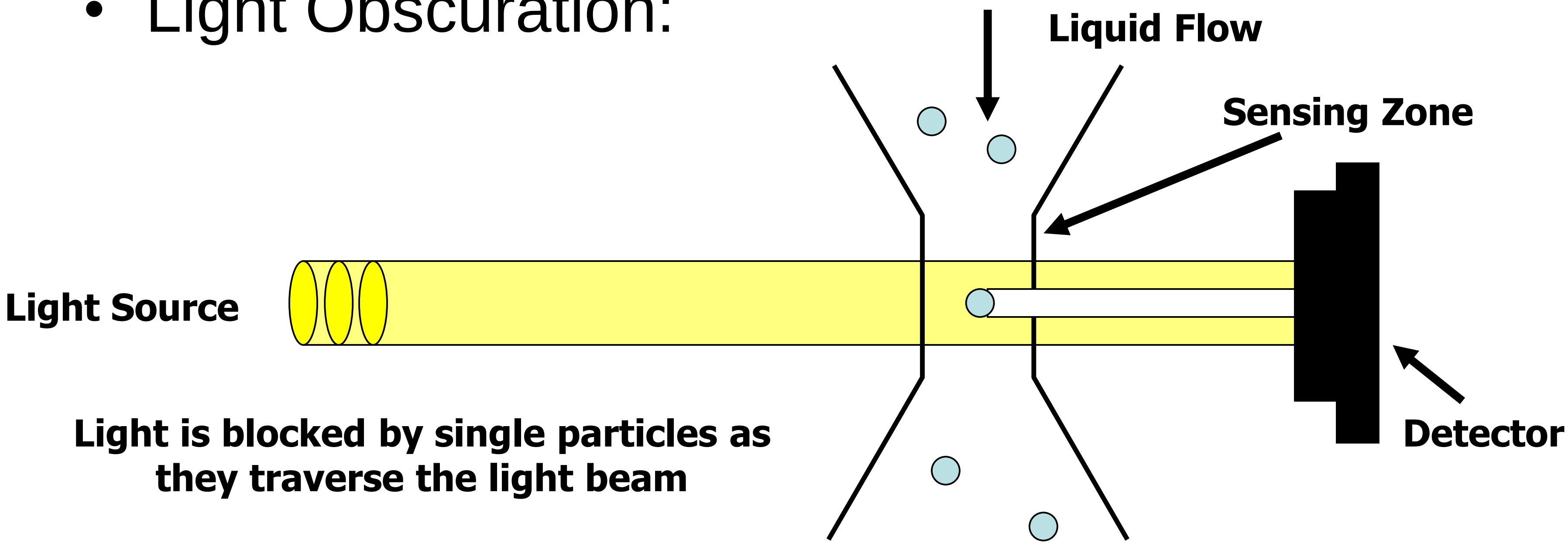
- Coulter Principle
  - Based on change in conductivity of aperture as particle traverses.
  - Requires conducting liquid.
  - Directly measures particle volume and counts.
  - High resolution
  - Used for blood cell counting more than industrial applications



© 2018 HORIBA, Ltd. All rights reserved.

Light Obscuration

- Light Obscuration:



Advantages:

- Particle count available
- USP<788> testing
- High resolution histogram

Disadvantages:

- Dilution required for particle size analysis
- Prone to cell clogging

© 2018 HORIBA, Ltd. All rights reserved.

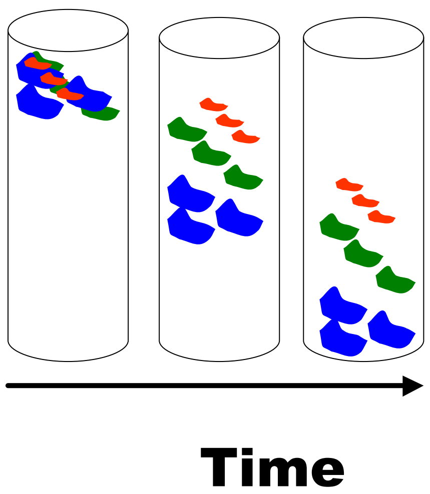
Sedimentation

- Stokes Law

$$D = \sqrt{\frac{18\mu V_p}{(\rho_p - \rho_l)g}}$$

V_p = Settling velocity of discrete particle
g = Gravity constant
ρ_p = Density of Particle
ρ_l = Density of Carrier Fluid
μ = Viscosity of Carrier Fluid

Sedimentation of same density material in a viscous medium



Note: assumes settling of spherical particle
Under-sizes compared to other techniques if non-spherical

© 2018 HORIBA, Ltd. All rights reserved.

Sedimentation Issues

- **Comparison of Brownian Motion and Gravitational Settling** **(Movement in 1 second; Particle density of 2.0 grams/cc)**

Particle Diameter (In micrometers)	Movement due to Brownian Motion		Movement due to Gravitational Settling
0.01	2.36	>>	0.005
0.25	1.49	>	0.0346
0.50	1.052	>	0.1384
1.0	0.745	~	0.554
2.5	0.334	<	13.84
10.0	0.236	<<	55.4

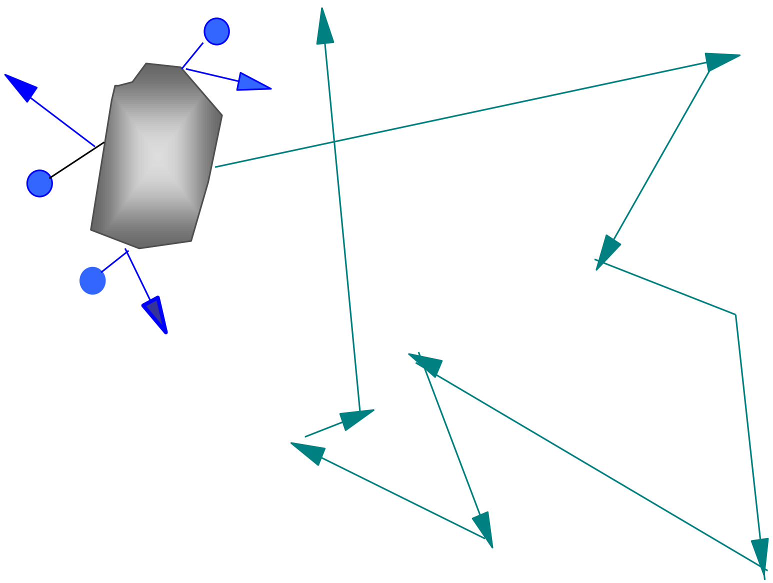
- Below 1 micrometer, Brownian motion becomes an appreciable factor in particle dynamics. Gravity sedimentation may not be an appropriate measurement technique for very small particles.

© 2018 HORIBA, Ltd. All rights reserved.

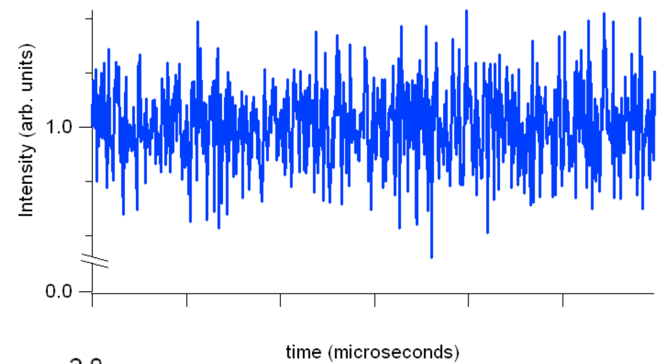
Dynamic Light Scattering

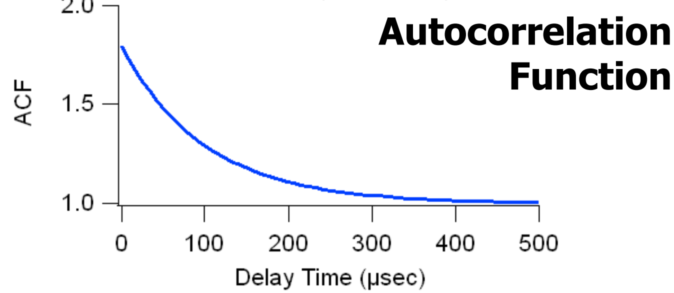
Most common technique for sub-micron sizing

Range: 1 nm – 1 μm*



Signal





Particles in suspension undergo Brownian motion due to bombardment by solvent molecules in random thermal motion.

Stokes-Einstein $$R_H = \frac{kT}{6\pi\eta D}$$

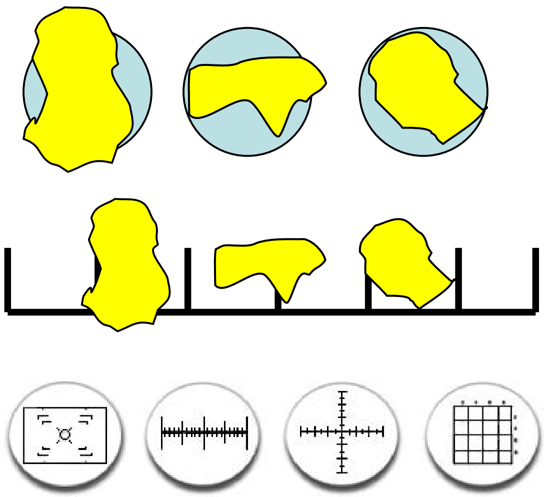
* Density dependent, when does settling become prominent motion?

Explore the future | Automotive Test Systems | Process & Environmental | Medical | Semiconductor | Scientific | HORIBA

© 2018 HORIBA, Ltd. All rights reserved.

Manual Microscopy

- Count particles in a given field of view
- Use graticule to obtain size
- Repeat this process for a number of fields
- At least hundreds of particles must be sized



Advantages:

- Simple
- Inexpensive
- Can see shape

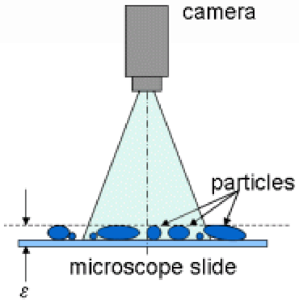
Disadvantages:

- Slow
- Measures very few particles
- Very tedious

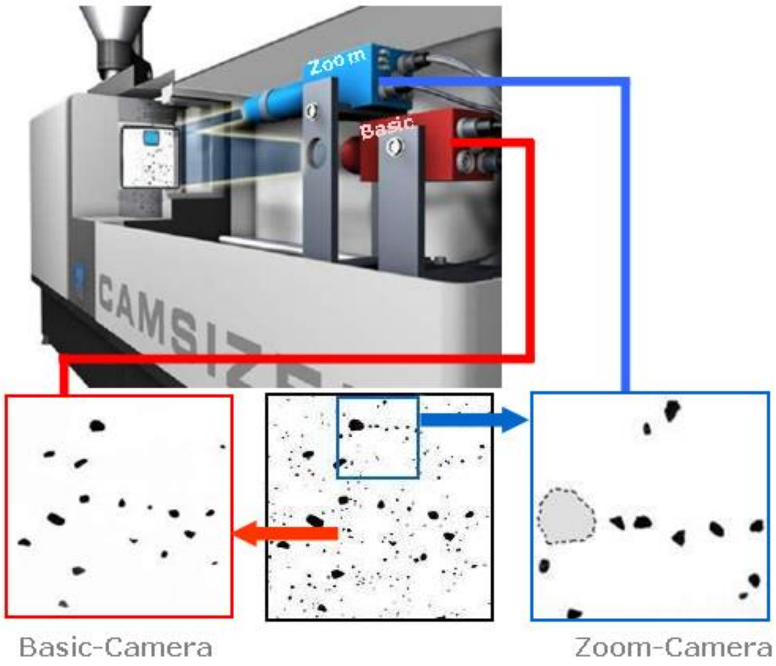
© 2018 HORIBA, Ltd. All rights reserved.

Automated Microscopy

Static:
Particles fixed on slide, stage moves slide



Dynamic:
Particles flow past camera(s)

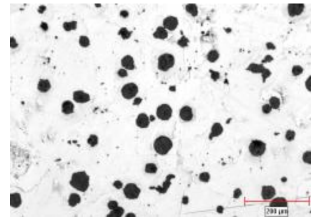


© 2018 HORIBA, Ltd. All rights reserved.

Automated Microscopy

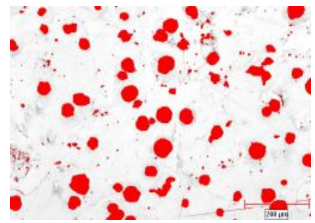
Objective & camera

Image Acquisition and enhancement



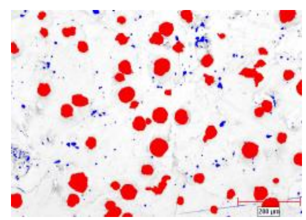
Subjective or automatic

Thresholding

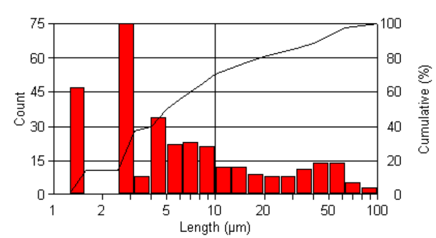


Decisions or black box

Image Processing



Measurements



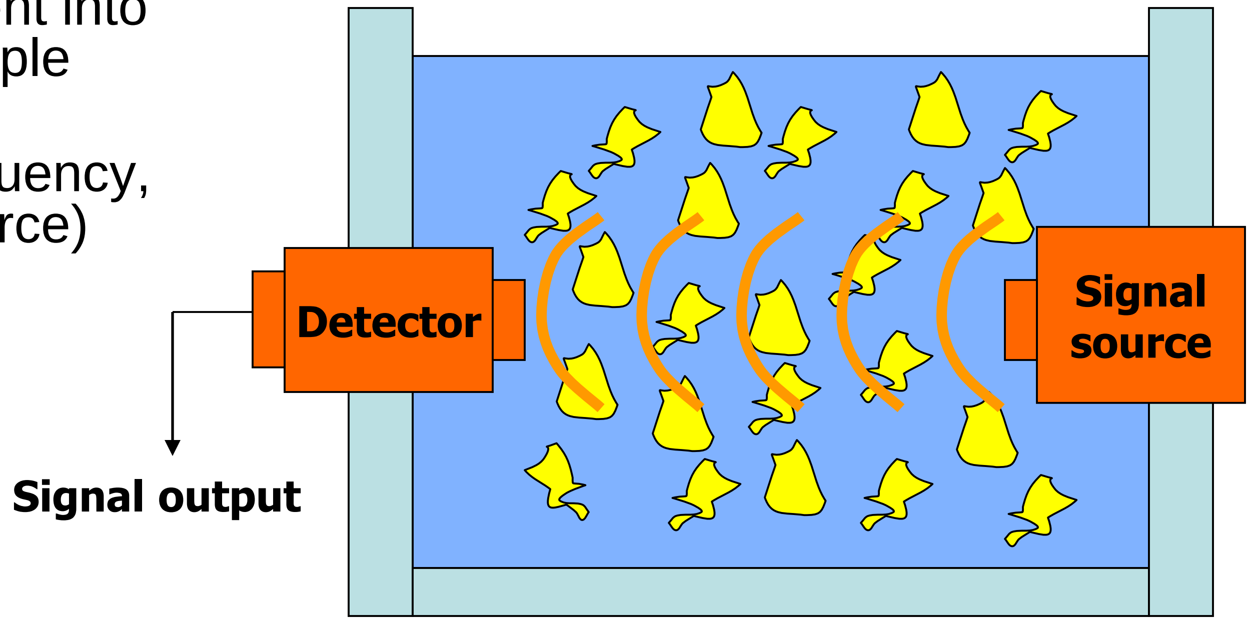
- Advantages:
- Quick size + shape info
- Statistically valid
- High resolution
- Particle images

- Disadvantages:
- Expense
- Knowing which numbers are important

© 2018 HORIBA, Ltd. All rights reserved.

Acoustic Spectroscopy

- Acoustic signal sent into concentrated sample
- Detector measure attenuation f (frequency, distance from source)



Advantages:

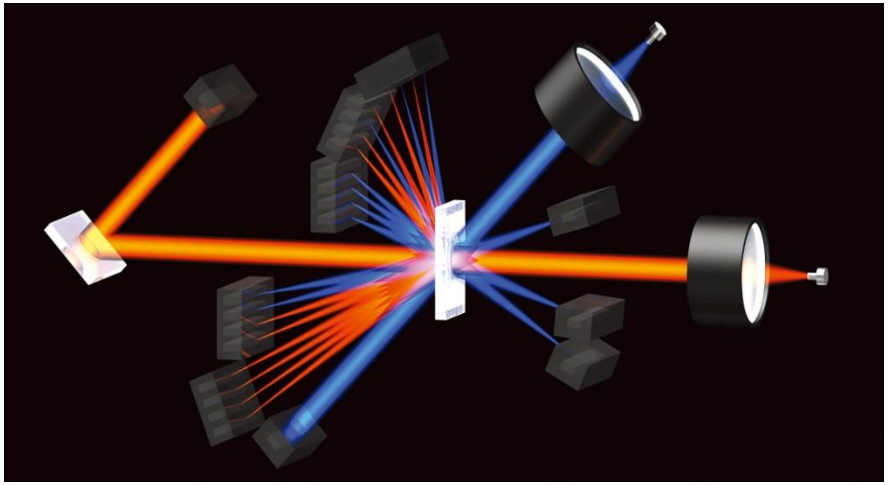
- Can accommodate high sample concentrations (no dilution)
- Rheological properties
- Also measure zeta potential

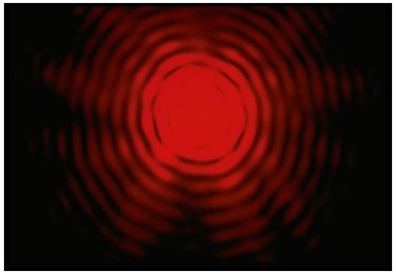
Disadvantages:

- Need at least 1 wt% particles
- Need to know wt%
- Minimum sample = 15 ml

© 2018 HORIBA, Ltd. All rights reserved.

Laser Diffraction





- •Converts scattered light to particle size distribution
- •Quick, repeatable
- •Powders, suspensions
- •Most common technique

© 2018 HORIBA, Ltd. All rights reserved.

Key Points

- Particle Analysis is about distributions
- Define terms (results) exactly
  - Volume vs. Number
- Different techniques give different answers since they measure different things
  - All are correct…
- Discuss results in terms of technique.

© 2018 HORIBA, Ltd. All rights reserved.

HORIBA Scientific

Thank you

© 2018 HORIBA, Ltd. All rights reserved.

Thank you

감사합니다

Cảm ơn

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

谢谢

நன்றி

ขอบคุณครับ

Obrigado

Σας ευχαριστούμε

Tack ska ni ha

شُكْرًا

Большое спасибо

Danke

Gracias

© 2018 HORIBA, Ltd. All rights reserved.