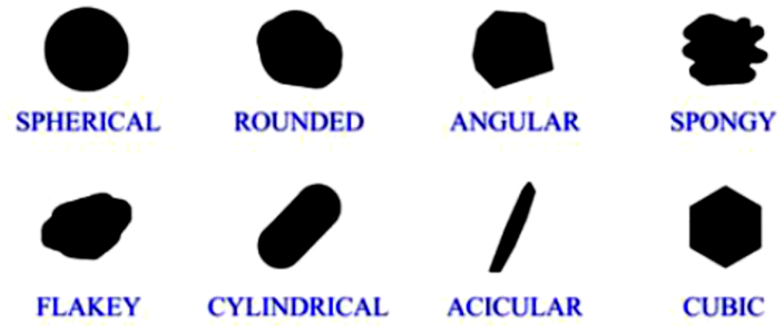
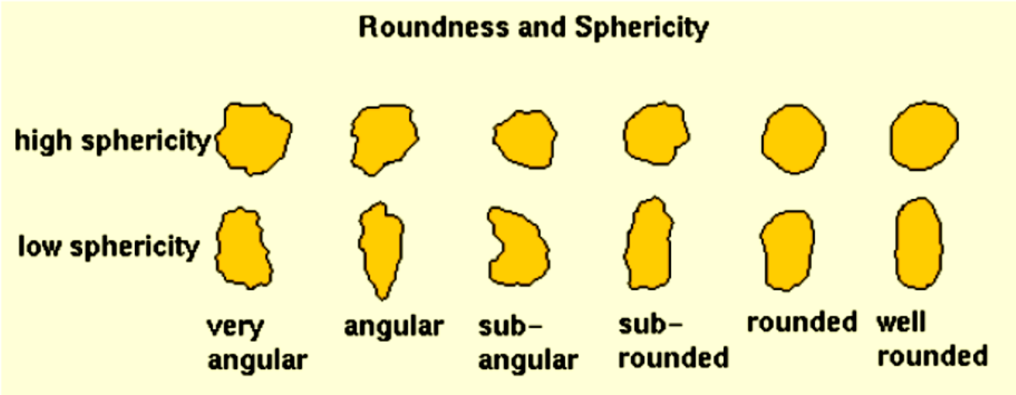
Characterization of Solid Particles

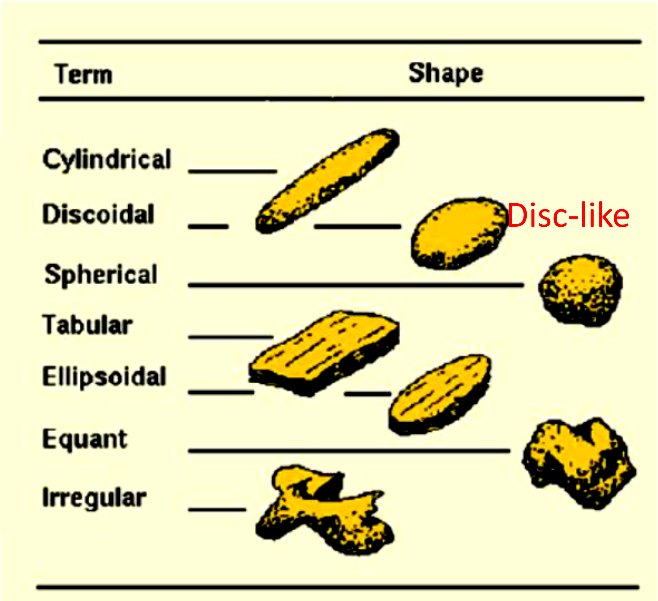
Particle Shapes and Measuring Techniques

CHARACTERIZATION OF SOLID PARTICLES

- SIZE
- SHAPE
- DENSITY







Single Particles: Particle shape

- The shape of an individual particle is expressed in terms of the sphericity φ_s, which is independent of particle size. The sphericity of a particle is the ratio of the surface-volume ratio of a sphere with equal volume as the particle and the surface-volume ratio of the particle. For a spherical particle of diameter D_p, φ_s =1; for a non-spherical particle, the sphericity is defined as

$$\boldsymbol{\varphi} = \frac{\textbf{surface area of sphere of same volume as particle}}{\textbf{surface area of particle}}$$

Sphericity can also be found from the following equation:

$$\varphi_s = \frac{6v_p}{S_p D_p}$$

- D_p: equivalent diameter of particle
- S_p: surface area of one particle
- v_p: volume of one particle

For many crushed materials, φ_s is between 0.6 and 0.8. For particles rounded by abrasion, φ_s may be as high as 0.95.

Notes

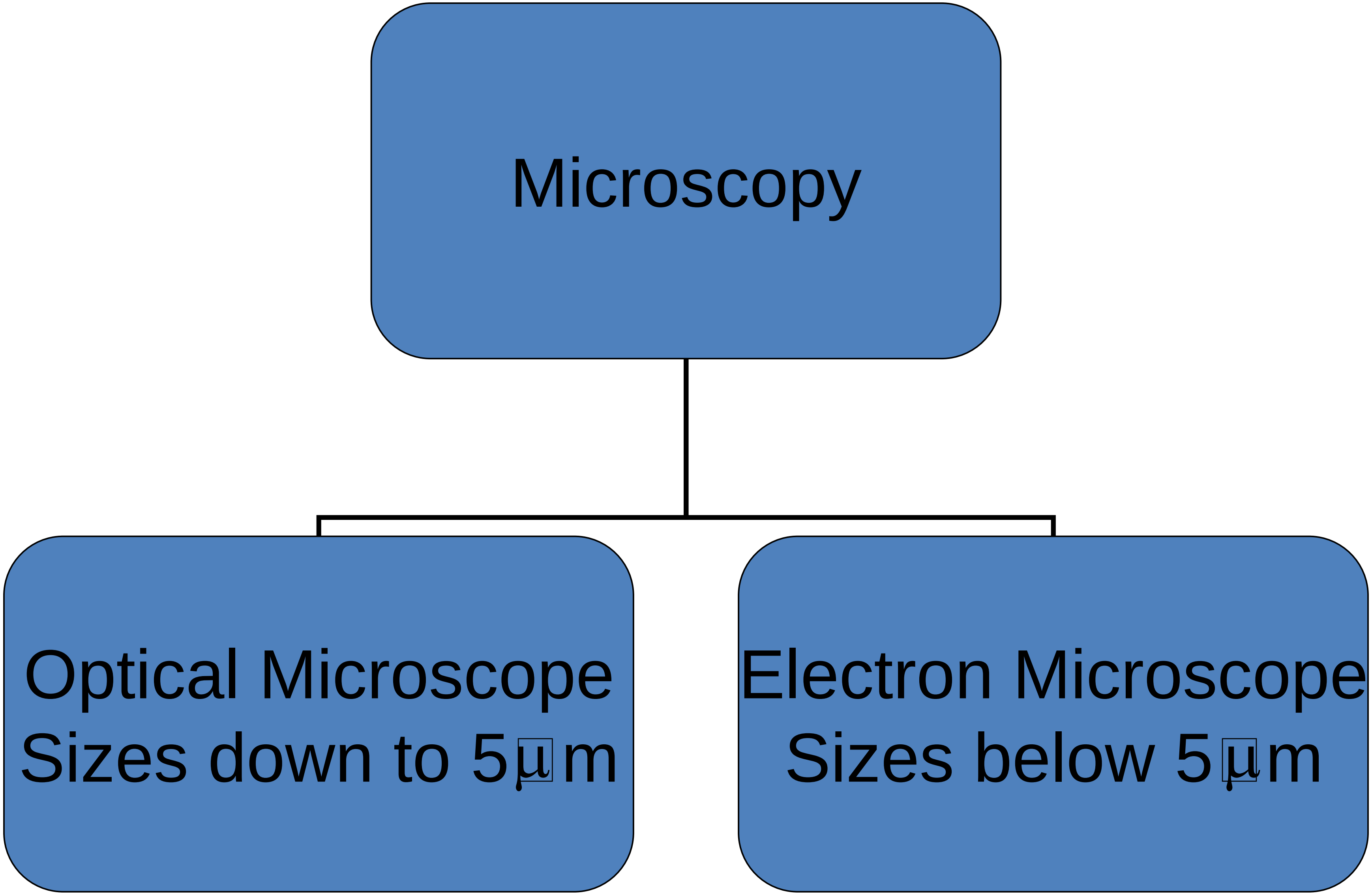
- The equivalent diameter is sometimes defined as the diameter of a sphere of equal volume.
- For fine particles, D_p is usually taken to be the nominal size based on screen analysis or microscopic analysis.
- The surface area is found from adsorption measurements or from the pressure drop in a bed of particles.

Particle size

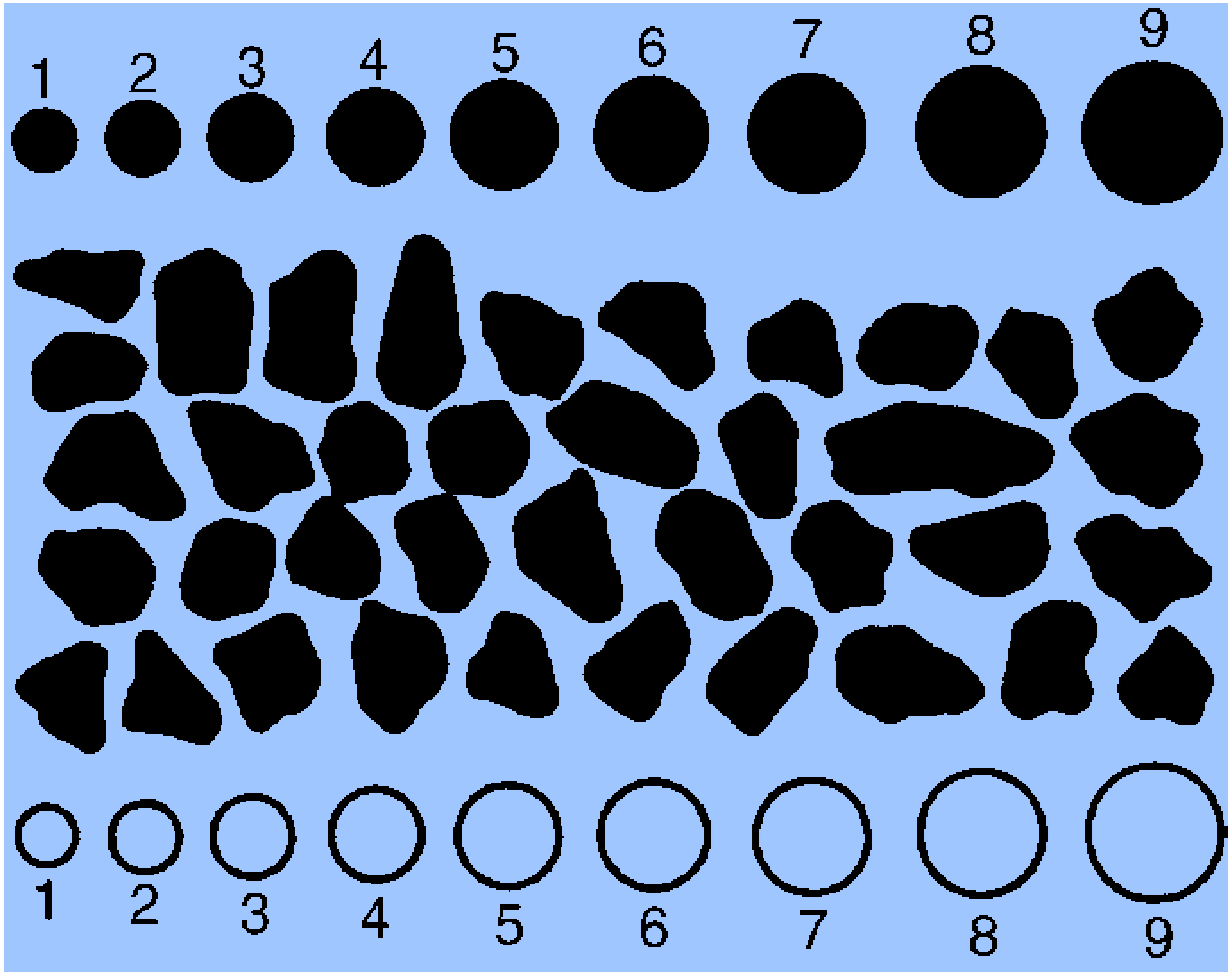
- In general "diameter" may be specified for any equidimensional particles.
- Particles that are not equidimensional, i.e. that are longer in one direction than in others, are often characterized by the second longest major dimension.
- For needle like particles, D_p would refer to the thickness of the particle, not their length

Measuring Techniques

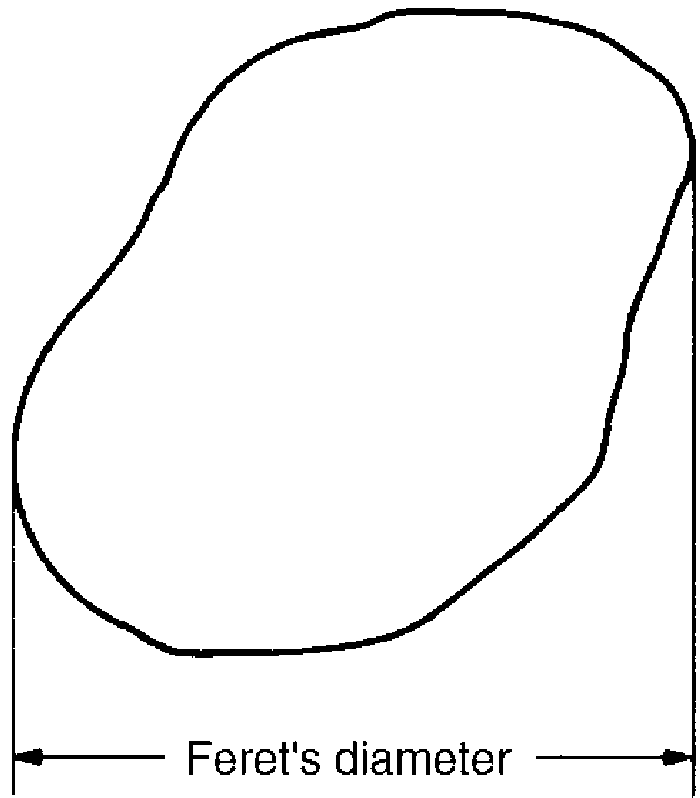
Microscopy


Microscopy
Optical Microscope
Sizes down to 5μm
Electron Microscope
Sizes below 5μm

Particle profiles and comparison circles

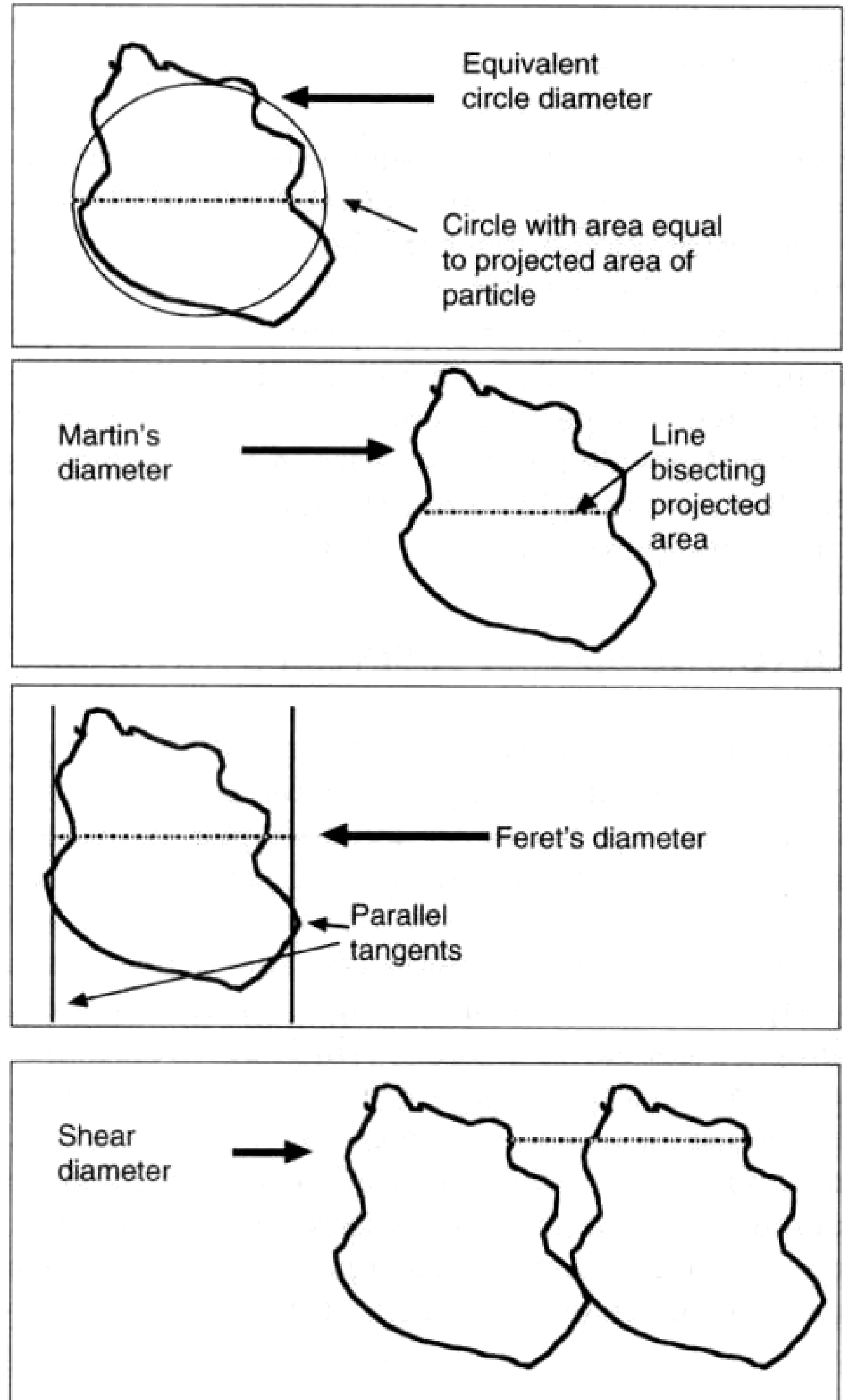


Feret's diameter_ statistical diameter



The mean distance apart of two parallel lines which are tangential to the particle in an arbitrarily fixed direction. Changing orientation will lead to a large number of Feret's diameter ≡ 'Microscopy dimension'

- Describing the size of a single particle. Some terminology about diameters used in microscopy.
- Equivalent circle diameter.
- Martin’s diameter.
- Feret’s diameter.
- Shear diameter.

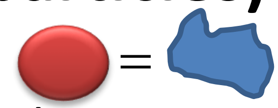


Particle Characterization

Size of equivalent sphere For Irregular Shape

PARTICLE CHARACTERISATION

Sizes of equivalent spheres (Single particles)

(a) The sphere of the same volume as the particle. 

(b) The sphere of the same surface area as the particle.

(c) The sphere of the same surface area per unit volume as the particle.

(d) The sphere of the same area as the particle when projected on to a plane perpendicular to its direction of motion.

(e) The sphere of the same projected area as the particle, as viewed from above, when lying in its position of maximum stability such as on a microscope slide for example.

(f) The sphere which will just pass through the same size of square aperture as the particle, such as on a screen for example.

(g) The sphere with the same settling velocity as the particle in a specified fluid.

Derived diameter

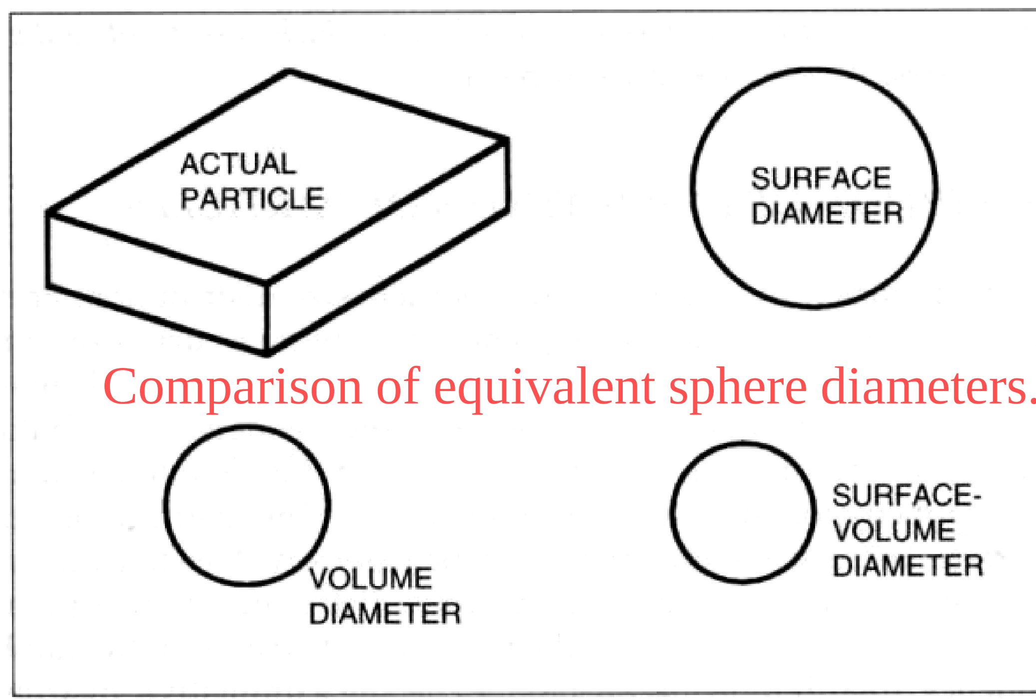
- Volume diameter, $d_v = \sqrt[3]{\frac{6V_p}{\pi}}$
- Surface diameter, $d_s = \sqrt{\frac{S_p}{\pi}}$
- Surface volume diameter, $d_{sv} = d_v^3 / d_s^2$
- Free falling diameter
- Projected area diameter

Describing the size of a single particle

- Regular-shaped particles

Shape	Sphere	Cube	Cylinder	Cuboid	Cone
Dimensions	Radius	Side length	Radius and height	Three side lengths	Radius and height

- The orientation of the particle on the microscope slide will affect the projected image and consequently the measured equivalent sphere diameter.
- Sieve measurement: Diameter of a sphere passing through the same sieve aperture.
- Sedimentation measurement: Diameter of a sphere having the same sedimentation velocity under the same conditions.



Comparison of equivalent sphere diameters.

Comparison of equivalent diameters

- The volume equivalent sphere diameter is a commonly used equivalent sphere diameter.
- Example: Coulter counter size measurement. The diameter of a sphere having the same volume as the particle.
- Surface-volume diameter is the diameter of a sphere having the same surface to volume ratio as the particle.

Measuring techniques

Sieving > 50 μm

Particle size and shape

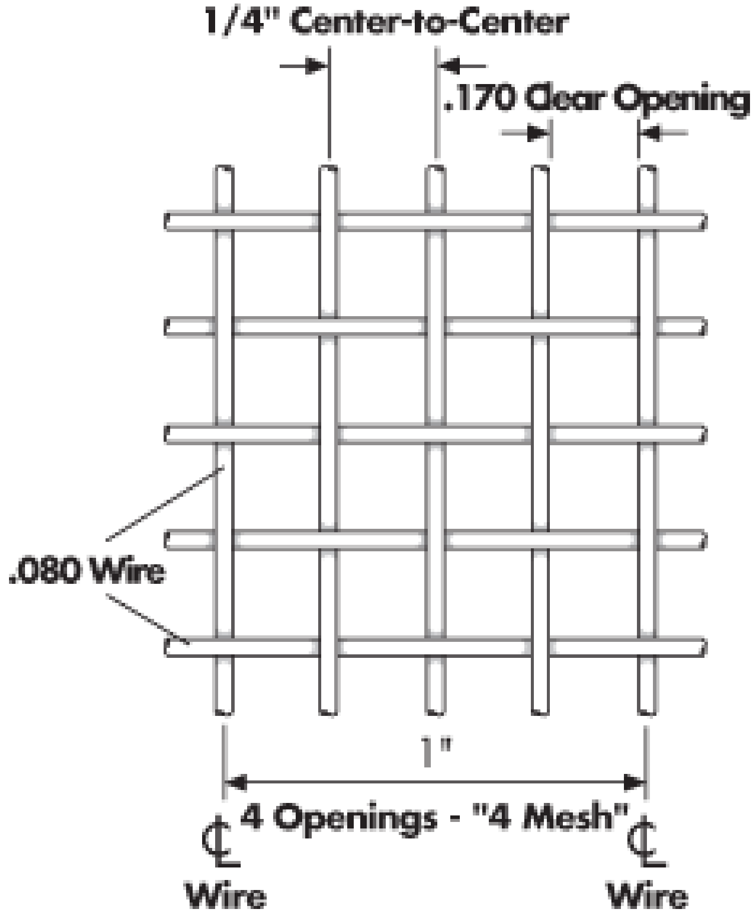


Table 1.1. Standard *sieve sizes*

British fine mesh (B.S.S. 410)[3]			I.M.M.[4]			U.S. Tyler[5]			U.S. A.S.T.M.[5]		
Sieve no.	Nominal aperture		Sieve no.	Nominal aperture		Sieve no.	Nominal aperture		Sieve no.	Nominal aperture	
	in.	μm		in.	μm		in.	μm		in.	μm
						325	0.0017	43	325	0.0017	44
						270	0.0021	53	270	0.0021	53
300	0.0021	53				250	0.0024	61	230	0.0024	61
240	0.0026	66	200	0.0025	63	200	0.0029	74	200	0.0029	74
200	0.0030	76							170	0.0034	88
170	0.0035	89	150	0.0033	84	170	0.0035	89			
150	0.0041	104				150	0.0041	104	140	0.0041	104
120	0.0049	124	120	0.0042	107	115	0.0049	125	120	0.0049	125
100	0.0060	152	100	0.0050	127	100	0.0058	147	100	0.0059	150
			90	0.0055	139	80	0.0069	175	80	0.0070	177
85	0.0070	178	80	0.0062	157	65	0.0082	208	70	0.0083	210
			70	0.0071	180				60	0.0098	250
72	0.0083	211	60	0.0083	211	60	0.0097	246	50	0.0117	297
60	0.0099	251							45	0.0138	350
52	0.0116	295	50	0.0100	254	48	0.0116	295	40	0.0165	420
			40	0.0125	347	42	0.0133	351	35	0.0197	500

British fine mesh (B.S.S. 410)[3]			I.M.M.[4]			U.S. Tyler[5]			U.S. A.S.T.M.[5]		
Sieve no.	Nominal aperture		Sieve no.	Nominal aperture		Sieve no.	Nominal aperture		Sieve no.	Nominal aperture	
	in.	μm		in.	μm		in.	μm		in.	μm
22	0.0275	699	20	0.0250	635	24	0.0276	701	25	0.0280	710
18	0.0336	853	16	0.0312	792	20	0.0328	833	20	0.0331	840
16	0.0395	1003				16	0.0390	991	18	0.0394	1000
14	0.0474	1204	12	0.0416	1056	14	0.0460	1168	16	0.0469	1190
12	0.0553	1405	10	0.0500	1270	12	0.0550	1397			
10	0.0660	1676	8	0.0620	1574	10	0.0650	1651	14	0.0555	1410
8	0.0810	2057				9	0.0780	1981	12	0.0661	1680
7	0.0949	2411				8	0.0930	2362	10	0.0787	2000
6	0.1107	2812	5	0.1000	2540	7	0.1100	2794	8	0.0937	2380
5	0.1320	3353				6	0.1310	3327			
						5	0.1560	3962	7	0.1110	2839
						4	0.1850	4699			
									6	0.1320	3360
									5	0.1570	4000
									4	0.1870	4760

Sieving >50 μm

- Set of sieves.
- Arrangement: ratio = 2 or $2^{1/2}$ or $2^{1/4}$
- Most common modern sieves are in sizes such that the ratio of adjacent sieve sizes is the fourth root of two (e.g. 45, 53, 63, 75, 90, 107 mm).
- Vibrator or shaker (vertical or horizontal vibration) .
- Fine particles may stick together (due to attractive forces) and block the screen.
- Standards: UK British standard, IMM standard, Tyler series

Particle Size Conversion Table

Sieve Designation		Nominal Sieve Opening		
Standard	Mesh	inches	mm	Microns
25.4 mm	1 in.	1.00	25.4	25400
22.6 mm	7/8 in.	0.875	22.6	22600
19.0 mm	3/4 in.	0.750	19.0	19000
16.0 mm	5/8 in.	0.625	16.0	16000
13.5 mm	0.530 in.	0.530	13.5	13500
12.7 mm	1/2 in.	0.500	12.7	12700
11.2 mm	7/16 in.	0.438	11.2	11200
9.51 mm	3/8 in.	0.375	9.51	9510
8.00 mm	5/16 in.	0.312	8.00	8000
6.73 mm	0.265 in.	0.265	6.73	6730
6.35 mm	1/4 in.	0.250	6.35	6350
5.66 mm	No.3 1/2	0.223	5.66	5660
4.76 mm	No. 4	0.187	4.76	4760
4.00 mm	No. 5	0.157	4.00	4000
3.36 mm	No. 6	0.132	3.36	3360
2.83 mm	No. 7	0.111	2.83	2830
2.38 mm	No. 8	0.0937	2.38	2380
2.00 mm	No. 10	0.0787	2.00	2000
1.68 mm	No. 12	0.0661	1.68	1680
1.41 mm	No. 14	0.0555	1.41	1410
1.19 mm	No. 16	0.0469	1.19	1190

Mesh	Micron	Inches
4	4760	0.185
6	3360	0.131
8	2380	0.093
12	1680	0.065
16	1190	0.046
20	840	0.0328
30	590	0.0232
40	420	0.0164
50	297	0.0116
60	250	0.0097
70	210	0.0082
80	177	0.0069
100	149	0.0058
140	105	0.0041
200	74	0.0029
230	62	0.0023
270	53	0.0021
325	44	0.0017
400	37	0.0015
625	20	0.0008
1250	10	0.0004
2500	5	0.0002

Reading Notes

- Larger sieve openings (1 in. to 1/4 in.) have been designated by a sieve "mesh" size that corresponds to the size of the opening in inches.
- Smaller sieve "mesh" sizes of 3 1/2 to 400 are designated by the number of openings per linear inch in the sieve.
- The following convention is used to characterize particle size by mesh designation:

  a "+" before the sieve mesh indicates the particles are retained by the sieve;

  a "-" before the sieve mesh indicates the particles pass through the sieve;

  typically 90% or more of the particles will lie within the indicated range.

For example, if the particle size of a material is described as -4 +40 mesh, then 90% or more of the material will pass through a 4-mesh sieve (particles smaller than 4.76 mm) and be retained by a 40-mesh sieve (particles larger than 0.420 mm). **If a material is described as -40 mesh, then 90% or more of the material will pass through a 40-mesh sieve (particles smaller than 0.420 mm.**

Sieving efficiency & rate of screening or passage of particles through sieve

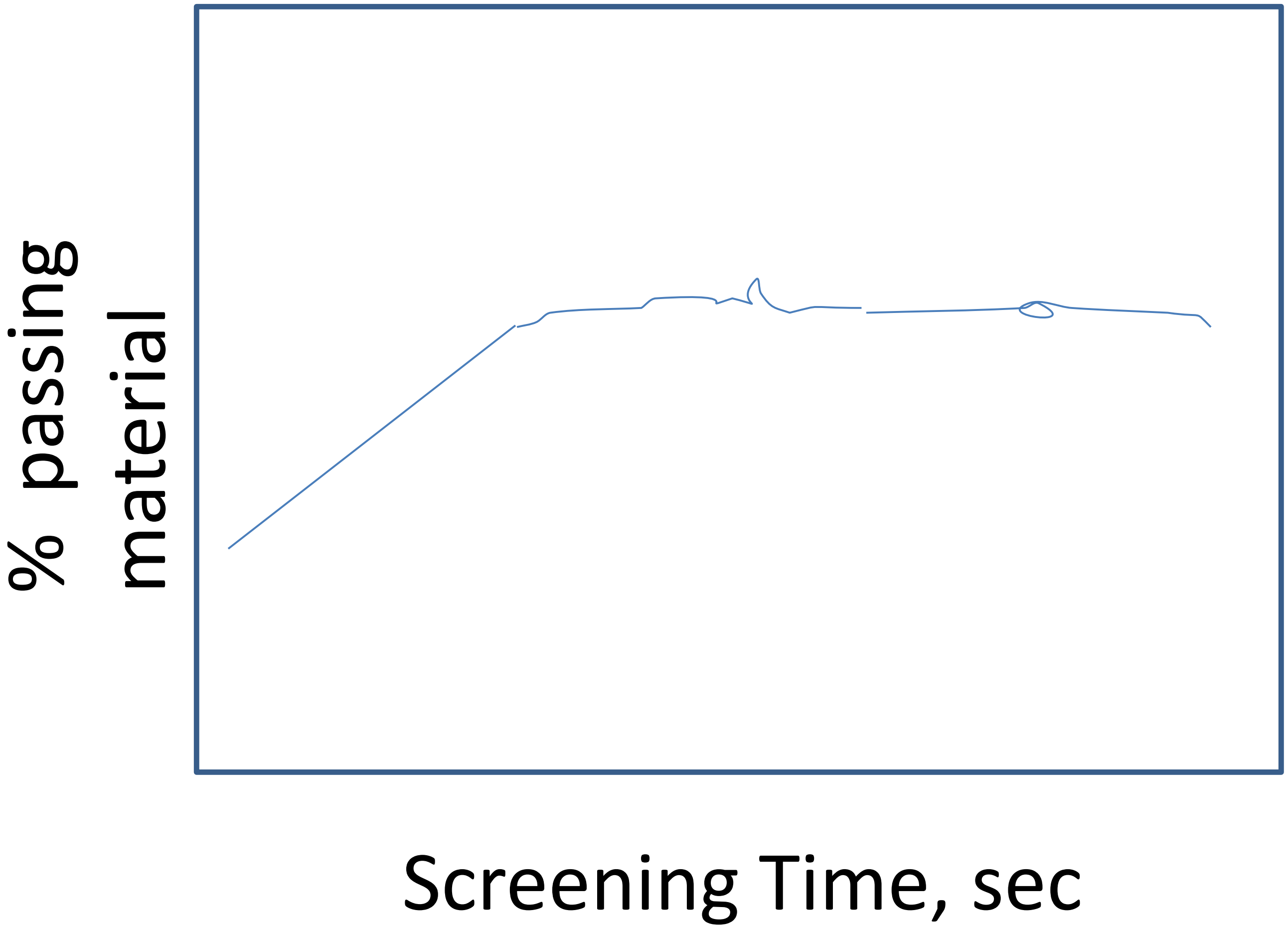
$$\eta_{sieving} = \frac{\text{wt of material which passes the screen}}{\text{wt of material which capable of passing}}$$

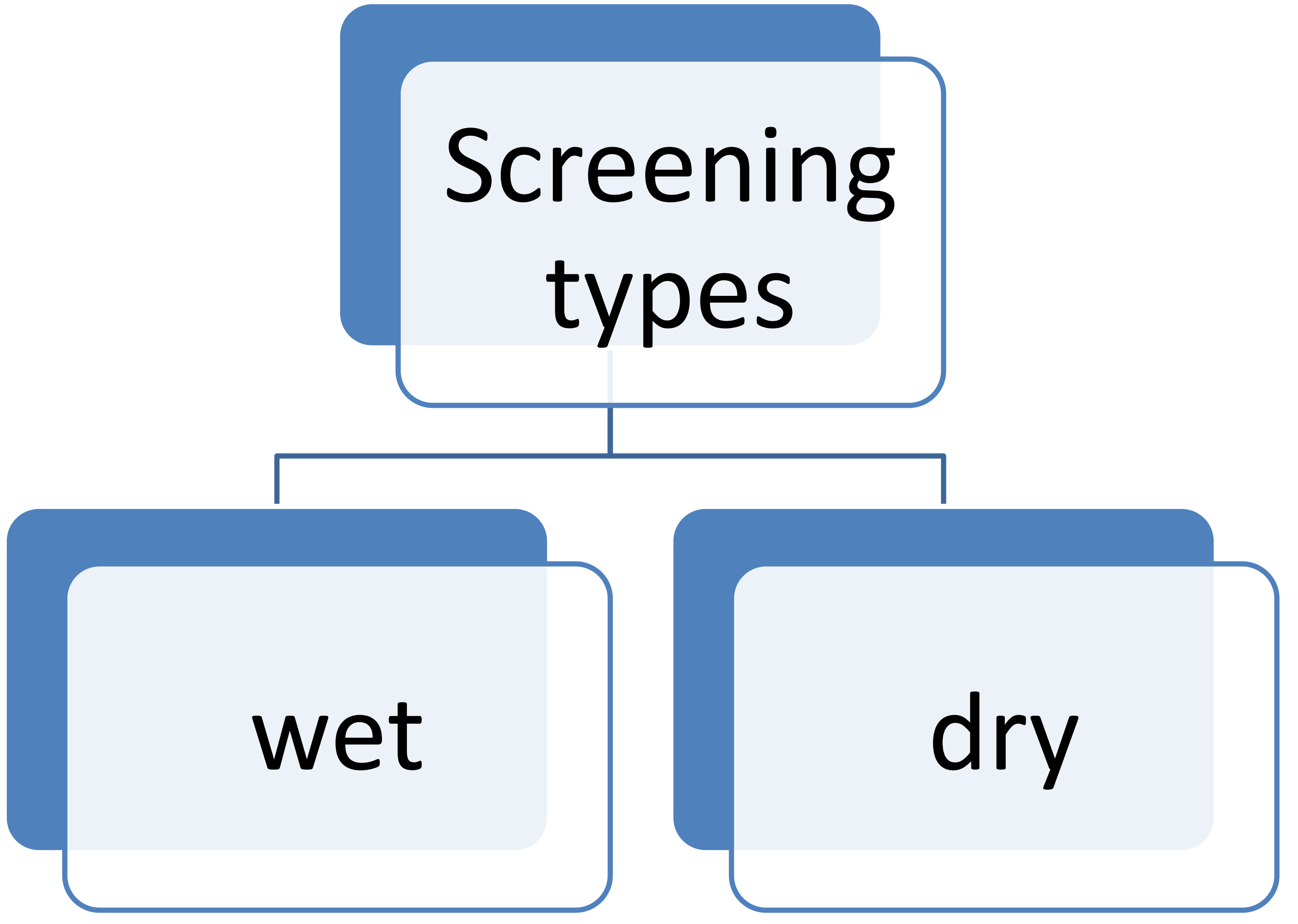
$$\text{rate of passage of particles} = \frac{dw}{dt} = -kw$$

where w is the mass of particles of a certain size on the screen.

mass of particles, $w_1 - w_2$, passing the screen in time t is $\ln\frac{w_2}{w_1} = -kt$;0r $w_2 = w_1 e^{-kt}$

General trend of screening process



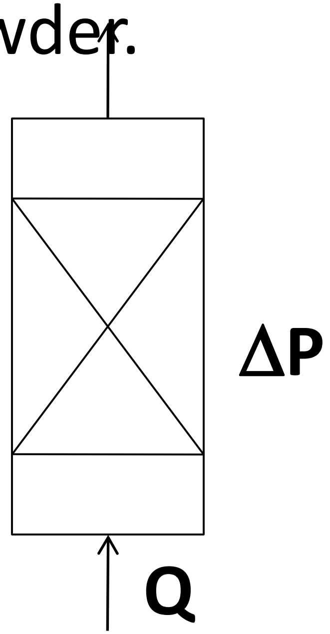

Screening types
wet
dry

Permeability methods (>1 μm)

- These methods depend on the fact that at low flow rates the flow through a packed bed is directly proportional to the pressure difference, the proportionality constant being proportional to the square of the specific surface of the powder.

- From this method it is possible to obtain the diameter of the sphere with the same specific surface as the powder.

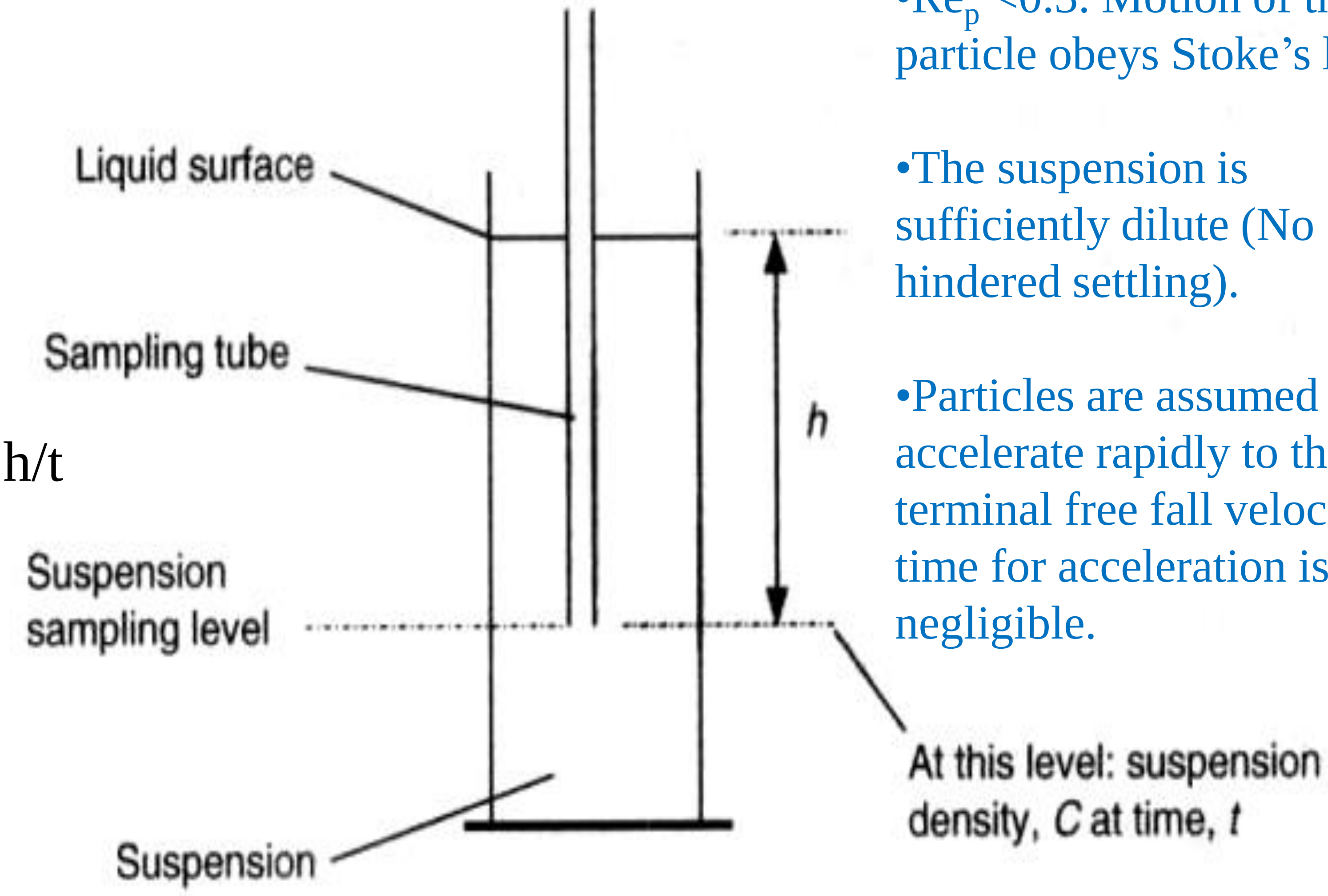
$$\frac{(-\Delta p)}{H} = 180\frac{(1-\varepsilon)^2}{\varepsilon^3}\frac{\mu U}{x^2}$$



- Further details will be given in next chapters.

Size analysis by Sedimentation pipette method

Note:
$U^* = h/t$



- $Re_p < 0.3$. Motion of the particle obeys Stoke's law.
- The suspension is sufficiently dilute (No hindered settling).
- Particles are assumed to accelerate rapidly to their terminal free fall velocity, time for acceleration is negligible.

C_o: original uniform suspension density.

Sampling point: C at time t after the start of settling.

Note: settling velocity

$u^* = h/t$

$$u^* = \frac{d_p^2(\rho_p - \rho_f)g}{18\mu}$$

At time t all particles traveling faster than h/t will have fallen below the sampling point.

C represents the suspension density for all particles which travel at a velocity <= h/t.

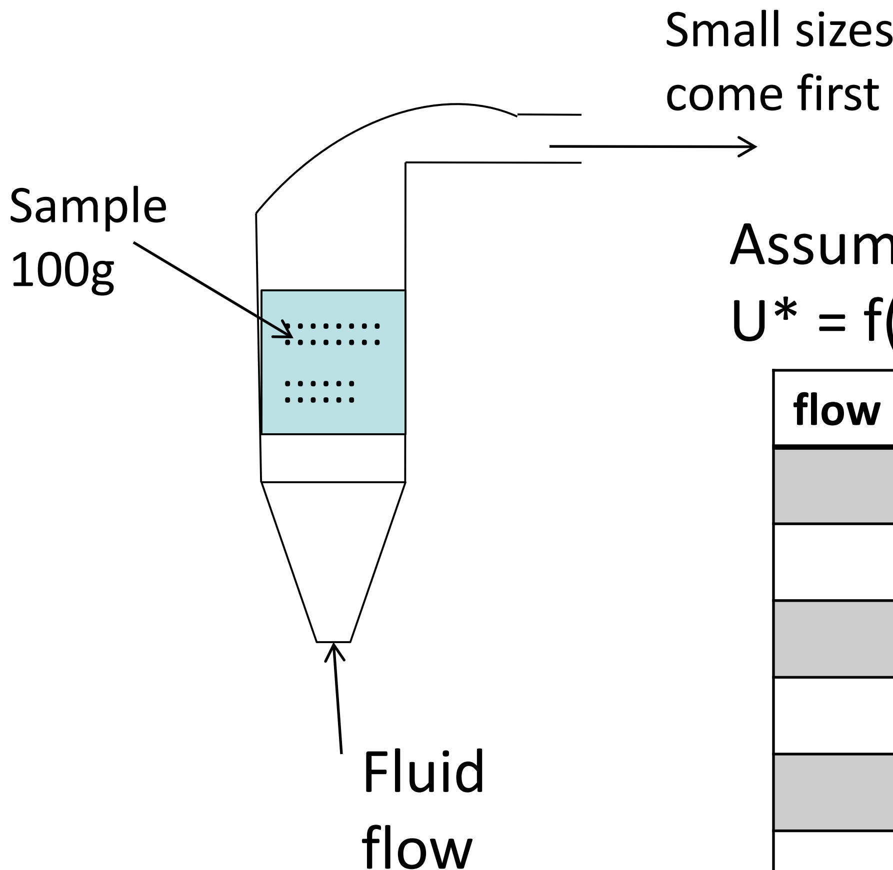
Re <0.3

$d_p = [18\mu h/t(\rho_p - \rho_f)g]^{1/2}$ Cum.

$$\text{cumulative mass fraction} = \frac{C}{C_0}$$

mass fraction = C/C_0Type equation here.

Size analysis by Elutriation



Assume Stokes regime U_f = U^* = $f(d_p)$ undersize

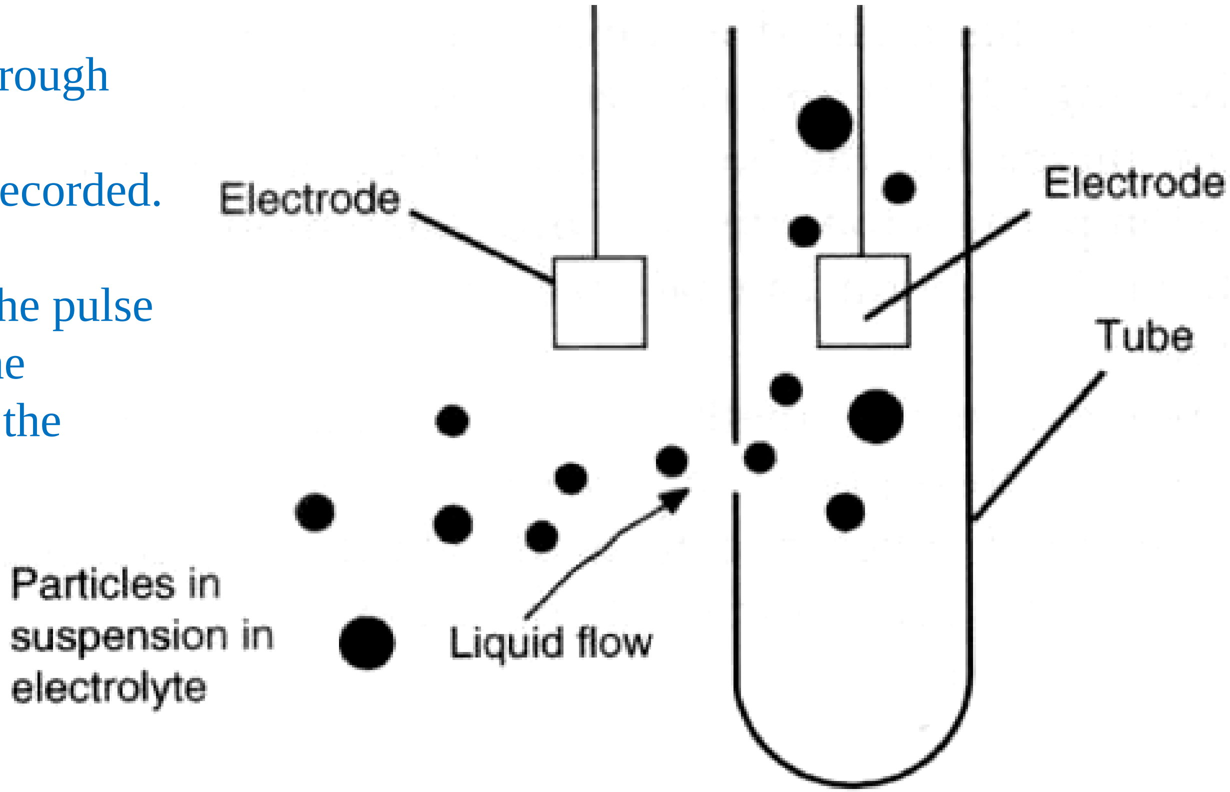
flow	mass	Uf
	100 g	

- Coulter Counter and Electrozone analyzer (1-1000μm)

As particle flow through the orifice,
a voltage pulse is recorded.

The amplitude of the pulse can be related to the volume of particle the orifice.

Particle range:
0.3-1000 μm.



- Schematic of electrozone sensing apparatus

Principle of Coulter Counter and Electrozone Analyser

- As particles enter the orifice they displace an equivalent volume of electrolyte, thereby producing a change in the electrical resistance of the circuit, the magnitude of which is related to the displaced volume.
- The consequent voltage pulse across the electrodes is fed to a multi-channel analyzer. The distribution of pulses arising from the passage of many thousands of particles is then processed to provide a particle (volume) size distribution.
- By using orifices of various diameters, different particle size ranges may be examined and the resulting data may then be combined to provide size distributions extending over a large proportion of the sub-millimetre size range.