

## Electrostatic charge interactions in ordered powder mixes

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A method is described for measuring the electrostatic charge generated in powders following contact with a plane substrate. The method uses a Faraday well connected to an electrometer and allows the specific charge of powders to be determined. Of the various drugs and excipients studied, most charged electronegatively following contact with glass surfaces, but became electropositive after contact with polyethylene surfaces. The charge interactions of drug and excipient powders modified the behaviour of ordered mixes formed in similar conditions to those of charge measurement. Powders with like charges formed less stable ordered mixes than those in which drug and excipient particles carried opposite charges. Following triboelectrification in an air cyclone constructed of brass, powders had charges at least 100 times greater than those formed after contact with glass surfaces. Optimization of the triboelectric charging conditions allowed ordered mixes to be prepared in which a maximum electronegative charge was applied to the excipient whilst the drug was given a maximum electropositive charge. Studies of segregation/stability showed that ordered mixes subjected to triboelectrification were less prone to segregation than uncharged powders.

In the absence of an externally applied electrical field, particles which come into contact with other particles or surfaces can acquire a charge which is retained when the surfaces separate. Production of an electrostatic charge by contact or frictional interaction of moving surfaces (Rudge 1913) is referred to here as triboelectrification.

Ordered mixes are formed between two sets of powder particles, usually with different size distributions (Hersey 1975). It has been shown previously by Rees & Staniforth (1978) that under certain circumstances segregation of ordered mixes can occur. The present study considers the role of electrostatic charges created by surface interactions between particles in relation to the formation and stability of ordered mixes.

### METHOD

Seven different pharmaceutical tableting excipients were studied, in addition to two model drug powders: potassium chloride less than 45  $\mu\text{m}$  diameter (BDH Ltd, Poole, Dorset) and salicylic acid less than 5  $\mu\text{m}$  diameter (micronized by West Australian Institute of Technology, Australia). The excipient powders investigated were:

#### *Four diluents/carriers:*

Dipac, a directly compressible sugar, (Amstar Corp., New York, U.S.A.)

Emdex, a spray-crystallized maltose-dextrose, (Edward Mendell Inc., New York, U.S.A.)

Recrystallized lactose, a dendritic form of  $\alpha$ -lactose monohydrate (Staniforth 1980a)

Sucrose, 425  $\mu\text{m}$ –620  $\mu\text{m}$  diameter size fraction (British Sugar Corporation, London, U.K.)

#### *a disintegrant:*

maize starch (May and Baker, Dagenham, Essex)

#### *a lubricant:*

magnesium stearate (BDH Ltd, Poole, Dorset)

#### *a glidant:*

talc (BDH Ltd, Poole, Dorset)

Each powder was tested individually, the charge on the particles being measured by pouring a known weight of powder on to a specially constructed Faraday well static charge detector (Fig. 1) connected to an electrometer (type 610 C, Keithley Instruments, Cleveland, U.S.A.). Four replicate determinations were made by pouring each powder into the inner container of the Faraday well so that the base was uniformly covered. Powders were poured at a constant rate of approximately  $0.5 \text{ g s}^{-1}$  off a glass surface in the form of a 250  $\text{cm}^3$  glass beaker and also off a plastic surface in the form of a 250  $\text{cm}^3$  polyethylene beaker.

A specially-constructed brass cyclone was used to

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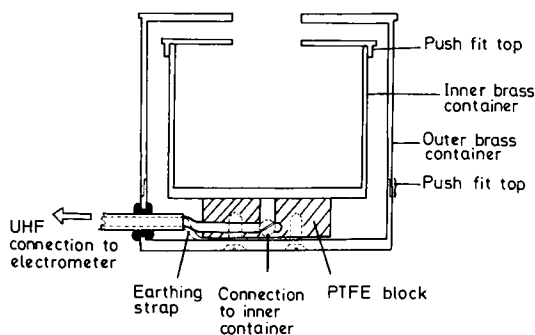


Fig. 1. Front elevation of Faraday well for determining static charge on powder particles.

triboelectrically charge the powder particles (Fig. 2). In each experiment the vortex-finder was set at a suitable height to remove the fluidizing air without removing any of the charged particles which left the cyclone through the dust outlet at the base. Fig. 3 shows the arrangement of the triboelectric charging apparatus. The turbulent air flow used to carry the powder into the cyclone was supplied by a blower (Model TL 91, B.V.C. Ltd, Leatherhead, Surrey) and the flow rate could be adjusted according to the differential pressure indicated by the manometer. Powder was supplied to the air stream from a vibratory feeder located in a pressurized container. The charge on the triboelectrically charged particles was measured by the method described above, except that the powder was introduced directly into the Faraday well, without pouring off an intermediate surface.

Ordered mixes were prepared using the excipients, Emdex, Dipac and recrystallized lactose and the model drug potassium chloride. The drug and excipient powders were initially mixed in a small ceramic mortar using a glass rod in place of the pestle, to reduce attrition. The ceramic mortar and glass stirrer were selected because preliminary measurements of triboelectric charges showed these surfaces produced a small frictional and contact charging effect in the powders studied. A homogeneous ordered mix was assumed to have been formed when the measured coefficient of variation of twenty samples was below 2%. Approximately 200 g of the ordered mixes were filled into the hopper of the triboelectric charging apparatus (Fig. 3). The triboelectric charging conditions such as air velocity and powder feed rate were optimized for each system to produce the maximum drug/excipient interparticle attraction. The stability of ordered mixes was studied in a model vibration system. Ordered mixes were

filled into a Perspex cylinder of 250 cm<sup>3</sup> volume. An inner Perspex cylinder was sectioned into 20 equidimensional interlocking units. This double cylinder allowed 20 samples to be removed at depths throughout the powder bed (Fig. 4). The cylinder was securely fixed to a vibration table which was vibrated at frequencies from 30 to 5000 Hz and at accelerations from 0.75 to 3 g. Preliminary experiments were performed to discover the vibration conditions which produced maximum segregation in different ordered mixes (Staniforth 1980b).

#### RESULTS AND DISCUSSION

The mean static charge was determined for each of the different powders poured into the Faraday well

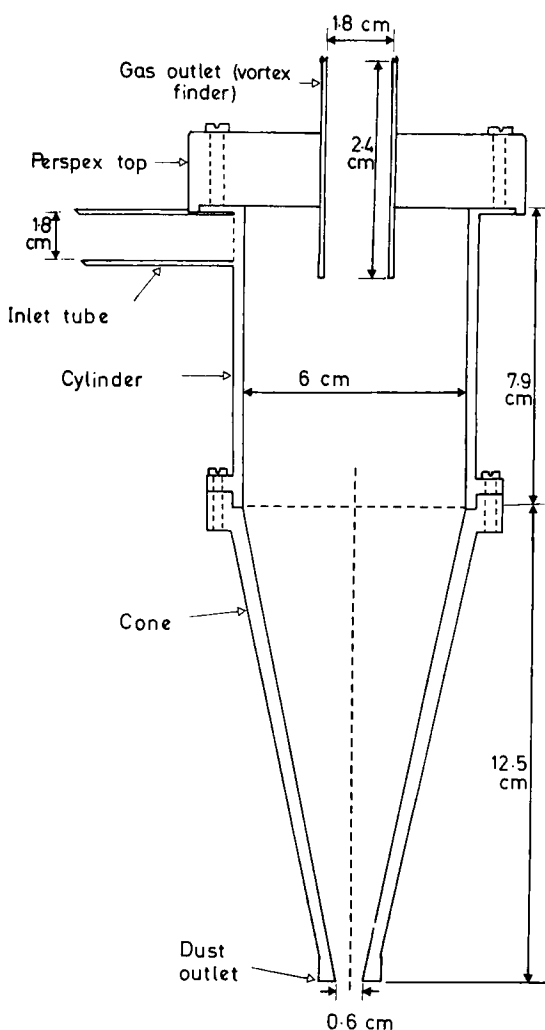


Fig. 2. Front elevation of brass charging cyclone for triboelectricification of drug and excipient powders.

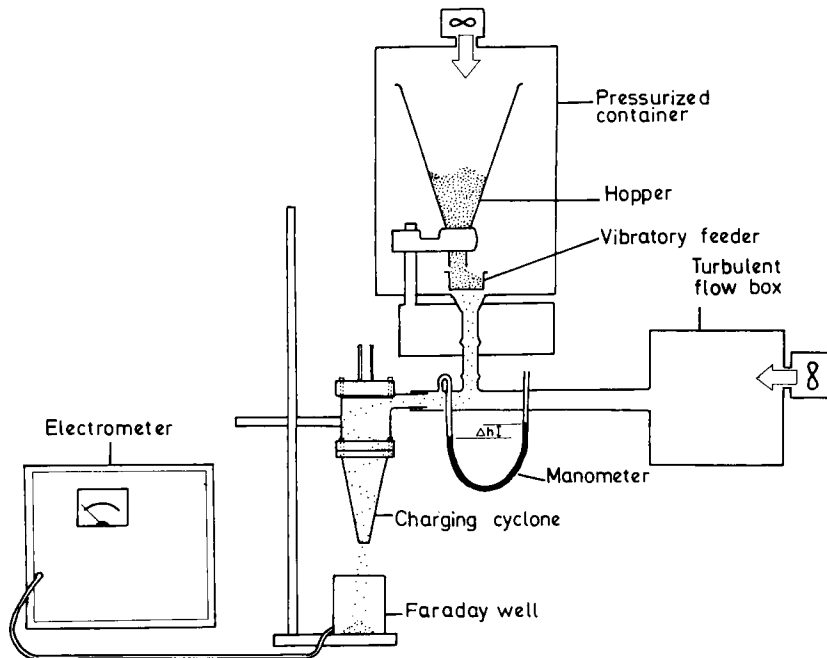


Fig. 3. Diagram showing the assembled charging apparatus with the charge-measuring apparatus in position.

off a glass surface (Table 1). Most of the powders tested carried a negative electrostatic charge but the magnitude of the charge differed significantly between materials. The mutual attraction between two sets of powder particles will be greater, the larger the difference in magnitude between the dissimilar electropositive and negative charges. This is best shown using a triboelectric series which is analogous to an electrochemical series. Although a triboelectric series is specific to a set of test conditions, it gives an indication of the possible interaction

between different powders. Table 2 shows a triboelectric series constructed from the charge values given in Table 1, following contact with a glass surface.

The charge measurements were repeated using a polyethylene surface to pour the powders into the Faraday well; this altered both the sign of the surface charge and the charge magnitude (Table 3). When

Table 1. Mean specific charges of different powders measured after pouring off a glass surface. Values are expressed in units of  $10^{-9} \text{ Cg}^{-1}$  to facilitate comparison of charges on different powders. Each value is the mean of five separate determinations.

Powder sample	Mean specific charge ( $10^{-9} \text{ Cg}^{-1}$ )	95% confidence limits	Variance
Dipac	-7.6	$\pm 1.6$	0.76
Emdex	-1.2	$\pm 0.45$	0.06
Recrystallized lactose	-2.9	$\pm 0.7$	0.15
250-500 $\mu\text{m}$ size fraction			
500-710 $\mu\text{m}$	-0.63	$\pm 0.14$	0.56
710-1000 $\mu\text{m}$	-0.4	$\pm 0.17$	0.83
180-250 $\mu\text{m}$	-7.6	$\pm 2.1$	1.36
90-180 $\mu\text{m}$	-9.7	$\pm 3.8$	4.31
0-90 $\mu\text{m}$	-7.7	$\pm 0.88$	23.39
Potassium chloride	-13.0	$\pm 1.1$	38.09
Sucrose	-2.4	$\pm 0.94$	0.26
Salicylic acid	-25.0	$\pm 1.8$	0.96
Starch	+0.13	$\pm 0.09$	0.24
Magnesium stearate	+8.8	$\pm 1.0$	0.31
Talc	-2.7	$\pm 0.47$	6.46

Table 2. Triboelectric series of different types of drug and excipient powders poured off a glass surface.

Electronegative	Electropositive
Salicylic acid (adherent, drug)	Starch (disintegrant excipient)
Potassium Chloride (adherent, drug)	Magnesium stearate (lubricant, excipient)
Recrystallized lactose 90-180 $\mu\text{m}$ (carrier, excip)	
Recrystallized lactose 0-90 $\mu\text{m}$ (carrier, excip)	
Recrystallized lactose 180-250 $\mu\text{m}$ (carrier, excip)	
Dipac (carrier, excipient)	
Recrystallized lactose 250-500 $\mu\text{m}$ (carrier, excip)	
Talc (glidant, excipient)	
Sucrose (carrier, model excipient)	
Emdex (carrier, excipient)	
Recrystallized lactose 500-710 $\mu\text{m}$ (carrier, excip)	
Recrystallized lactose 710-1000 $\mu\text{m}$	

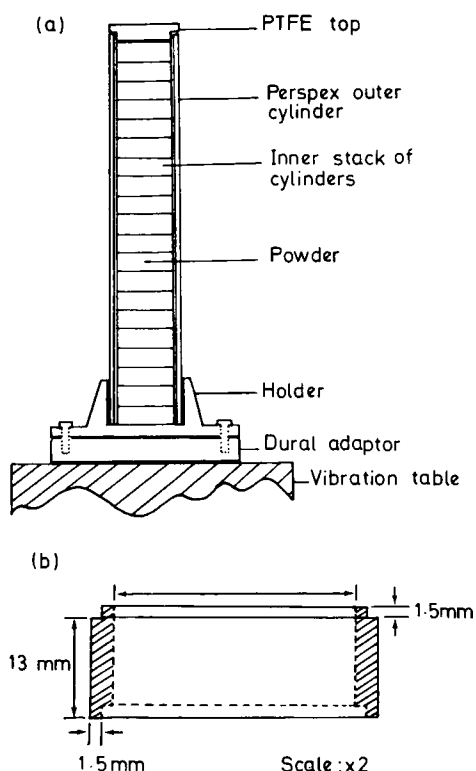


Fig. 4. Double cylinder allowing 20 samples to be removed at depths throughout the powder bed.

poured off a polyethylene surface most of the particles charged positively. Glass and polyethylene surfaces produce charges of different signs on the same powder because they are at opposite ends of a triboelectric series. Glass is more electropositive than most materials and therefore produces electronegative image charges on most other surfaces, whereas polythene is more electronegative and tends to produce electropositive charges on most powder surfaces (Staniforth 1980b).

The fact that different surfaces produce different charge effects in pharmaceutical powders has significant implications in the context of ordered mixing. The model drug, salicylic acid and potassium chloride, which charge electronegatively when contacted with glass surfaces will not be attracted to the surfaces of excipient carriers such as Emdex, lactose and Dipac which also charge electronegatively (Table 1). Thus, combinations of these drugs and excipients mixed in glass containers would be unlikely to form stable ordered mixes. In contrast, when processed in a polyethylene or Perspex blender some excipients such as Emdex and lactose charged

electropositively (Table 3) and would be expected to form stable ordered mixes with the electronegatively charged model drug particles.

The effect of such charge interactions on the formation of stable ordered mixes was assessed by studying systems containing 1% potassium chloride and Dipac, Emdex or lactose mixed in a Perspex blender. With potassium chloride, only Emdex and lactose formed stable ordered mixes that were capable of withstanding vibrational segregation (Staniforth 1980b). This confirms that the positive surface charge on the Emdex and lactose and the negatively-charged potassium chloride particles contributed to the formation of non-segregating mixes, whereas the negatively-charged Dipac interacted with the electronegative potassium chloride to form unstable ordered mixes.

Electrostatic interactions can be used to explain the behaviour of other ordered mixes. Lai & Hersey (1979) found that magnesium stearate caused 'stripping' of drug particles from carrier excipient particles in ordered mixes of salicylic acid and sucrose. This phenomenon may be explained by the electrostatic surface properties of the constituent powders. Our results show that both salicylic acid and sucrose developed electronegative surface charges when contacted with glass (Table 1) whereas magnesium stearate was strongly electropositive. In competition for active adherence sites on the carrier powder surface, the electropositive magnesium stearate would be strongly attracted to the electronegative

Table 3. Mean specific charge on different powders measured after pouring off a polyethylene surface.

Powder sample	Mean specific charge ( $10^{-9} \text{ Cg}^{-1}$ )	95% Conf. lim.	Variance
Dipac	-6.1	$\pm 0.32$	0.03
Emdex	+4.7	$\pm 0.40$	4.29
Recrystallized lactose			
0-90 $\mu\text{m}$	+17.0	$\pm 1.8$	0.91
90-180 $\mu\text{m}$	+24.0	$\pm 1.7$	0.75
180-250 $\mu\text{m}$	+30.0	$\pm 0.64$	0.11
250-500 $\mu\text{m}$	+16.0	$\pm 1.6$	0.79
500-710 $\mu\text{m}$	+28.0	$\pm 3.6$	3.84
710-1000 $\mu\text{m}$	+7.7	$\pm 1.0$	0.27
Recrystallized lactose (whole size range)	+11.0	$\pm 1.5$	0.65
Potassium chloride ( $>45 \mu\text{m}$ )	-0.21	$\pm 0.4$	4.80
Potassium chloride ( $>45 \mu\text{m}$ )	-6.9	$\pm 0.15$	0.62
Sucrose	+0.96	$\pm 0.01$	0.01
Salicylic acid	-34.76	$\pm 3.33$	7.31
Starch	+1.85	$\pm 0.16$	0.01
Magnesium stearate	+4.55	$\pm 3.16$	6.58
Talc	+10.9	$\pm 3.60$	8.55

sucrose causing the electronegative salicylic acid particles to become dislodged or to become re-located at weaker adherence sites on the sucrose surface.

In an attempt to enhance the stability of ordered mixes based on Dipac, Emdex or lactose with the model drug potassium chloride, we used the triboelectric charging apparatus (Fig. 3) to modify surface charges on the powder particles (Table 4). Each powder, with the exception of magnesium stearate, showed increased electronegativity after charging in the brass cyclone. Static charges on most of the powder were increased by a factor of at least 100 when triboelectrically charged compared with the

At a flow rate of  $0.14 \text{ g s}^{-1}$  and a fluidizing air pressure of 63 mm, potassium chloride charged electronegatively as it did when contacted with a glass surface (Tables 1 and 5). However, when triboelectrification was continued for 35 s or longer, charge reversal occurred and the potassium chloride became electropositive. Varying the powder flow rate altered both the mean specific charge and the time at which charge reversal occurred, at the maximum flow rate, charge reversal was instantaneous (Table 5). Charge reversal may have occurred as a result of potassium chloride particles rubbing against other potassium chloride crystals, rather than on the brass cyclone wall. However, a possible

Table 4. Triboelectric charging of drug and excipient powders in an earthed brass cyclone. The air flow rate was kept constant as represented by a pressure differential of 62 mm. Values are expressed in units of  $10^{-9} \text{ Cg}^{-1}$  to facilitate comparison with Table 1.

Powder sample	Mean specific charge ( $10^{-9} \text{ Cg}^{-1}$ )	95% Conf. Lim.	Mean specific charge rate (Amp)	Variance	Mean flow rate ( $\text{g s}^{-1}$ )
Dipac	-130.0	$\pm 23$	$6.3 \times 10^{-9}$	0.02	0.20
Emdex	-1,300.0	$\pm 46$	$45 \times 10^{-9}$	0.06	0.23
Recrystallized lactose 250-500 $\mu\text{m}$ size fraction	-130.0	$\pm 35$	$7.8 \times 10^{-9}$	0.04	0.13
Recrystallized lactose 500-710 $\mu\text{m}$ size fraction	-470.0	$\pm 16$	$29 \times 10^{-9}$	0.01	0.07
Recrystallized lactose 710-1000 $\mu\text{m}$ size fraction	-360.0	$\pm 63$	$13 \times 10^{-9}$	0.13	0.04
Potassium chloride	-550.0	$\pm 110$	$54 \times 10^{-9}$	0.34	0.14
Sucrose	-510.0	$\pm 230$	$3.7 \times 10^{-9}$	1.73	0.35
Starch	-200.0	$\pm 120$	$2.6 \times 10^{-9}$	0.44	0.19
Magnesium stearate	+17	$\pm 14$	$39 \times 10^{-9}$	2.03	0.003
Talc	-49	$\pm 26$	$0.85 \times 10^{-9}$	0.64	0.17

measured charge following contact with a glass surface (Table 1). The mean specific charge rate, shown in column 4 of Table 4 is synonymous with the measured current since Coulomb per second is a definition of the ampère. The current is determined firstly by the charge acquired due to triboelectrification and secondly by the flow rate of powder into the air cyclone since this influences the amount of frictional contact between individual particles and the cyclone wall.

alternative explanation is that charge reversal occurred due to mechanical fracture of potassium chloride crystals during triboelectrification; this type of mechanism is known to produce massive particle-charging in crystals such as mica (Hendricks 1973). In a particle size analysis of potassium chloride powder before and after passage through the cyclone it was found that the median particle diameter in the feed was  $6 \mu\text{m}$  whereas the median diameter in the product was  $4 \mu\text{m}$ . This shows that the triboelectrifi-

Table 5. Effect of feed rate on the triboelectrification of potassium chloride powder ( $<45 \mu\text{m}$  diameter).

Mean flow rate ( $\text{g s}^{-1}$ )	Mean specific charge ( $10^{-9} \text{ Cg}^{-1}$ )	95% Conf. Lim.	Variance	Mean specific charge rate (Amp)	Differential air pressure (mm)	Charge reversal conditions	
						Maximum electronegative charge ( $\text{Cg}^{-1}$ )	Time at which charge reversal occurred (s)
0.14	-550	$\pm 11$	0.34	$54 \times 10^{-9}$	63	Not measured	35
0.71	+34	$\pm 3.4$	5.30	$1.7 \times 10^{-9}$	63	$-100 \times 10^{-9}$	1-4
0.97	+70	$\pm 4.2$	0.21	$3.9 \times 10^{-9}$	63	—	0
4.63	+65	$\pm 3.9$	3.59	$25 \times 10^{-9}$	63	$-100 \times 10^{-9}$	5-6

cation process causes some deformation and fracture of particles which may affect the electrostatic charge.

Altering the powder feed rate of Dipac and Emdex caused changes in magnitude of the charge produced, with the maximum charge developing at intermediate feed rates (Table 6). High feed rates decreased the particle charge, possibly by reducing the number of particle-cyclone collisions, critical to the triboelectrification process. Conversely, a very low feed rate for Dipac reduced the particle charge, probably by lowering the impact velocity on the cyclone wall; at very low air speeds the reduced impact velocity will decrease the amount of deformation and consequently the charge magnitude.

Over a period of time the charge accumulated on powder particles is dissipated; charge leakage appears to be dependent on the composition of the charged material and can vary from a few seconds to several years depending on the resistivity of the material. In the powders studied here most of the charge is dissipated within a few minutes of triboelectrification.

Based on the results in Table 5 and 6, suitable experimental conditions were selected to achieve maximum electrostatic attraction between the model drug and the respective excipient; air velocities and feed rates were adjusted (Table 7) to produce the highest possible electropositive charge on the potassium chloride particles, whilst at the same time

producing the maximum electronegative charge on the excipient powder. The segregation behaviour of ordered mixes prepared with and without triboelectrification was compared using vibration conditions which had previously been shown to produce marked segregation in non-triboelectrified mixes (Staniforth 1980b).

A non-triboelectrified ordered mix of Dipac plus 0.5% potassium chloride had a marked segregation tendency, whereas this was greatly reduced when the same system was triboelectrified before vibration (Table 8). An ordered mix containing recrystallized lactose and 0.5% potassium chloride was also found to undergo less segregation when the powders had been charged triboelectrically (Table 8). Similar results were obtained in the case of highly segregating systems such as Emdex or Dipac mixed with 10% potassium chloride: in both cases, charging reduced the segregation tendency (Table 8).

In addition to reducing the overall segregation tendency of different ordered mixes, triboelectrification also reduced the error limits between powder samples. A reduction in the error limits is of practical importance in pharmaceutical systems where content uniformity of dosage forms is required.

We believe several mechanisms to be responsible for the reduced segregation tendency of ordered mixes after triboelectric charging. The increased electrostatic attraction between oppositely-charged

Table 6. Effect of feed rate and differential air pressure on the triboelectrification of different excipient powders.

Powder sample	Mean feed rate (gs <sup>-1</sup> )	Differential air pressure (mm)	Mean specific charge (10 <sup>-9</sup> Cg <sup>-1</sup> )	95% Conf. Lim.	Var.	Mean specific charge rate (10 <sup>-9</sup> Amp)
Dipac	0.04	62	-20	±2.5	1.85	0.07
	0.13	62	-230	±9.9	0.29	0.11
	0.14	20	-220	±7.8	0.18	0.17
	0.20	62	-130	±2.3	0.02	6.3
	0.21	45	-470	±3.9	4.47	0.55
	0.71	62	-48	±2.5	1.88	2.7
	3.56	62	-23	±2.8	0.02	3.4
Emdex	0.19	75	-1200	±18.4	0.01	58
	0.23	63	-1300	±45.7	0.06	45
	0.63	63	-780	±14.8	0.64	73
	1.81	63	-390	±8.9	0.23	150
Recrystallized lactose, 250-500 µm size fraction	0.02	56	-560	±24.5	1.77	9.5
	0.13	58	-190	±58.8	0.10	12
	0.13	64	-130	±35.3	0.04	7.8
	0.31	56	-66	±22.7	1.35	3.5
Recrystallized lactose, 500-710 µm size fraction	0.07	62	-470	±15.9	0.01	29
	0.18	63	-310	±82.7	0.20	23
	0.95	63	-68	±8.7	0.22	6.8
Recrystallized lactose, 710-1000 µm size fraction	0.04	63	-360	±63.0	0.13	13
	0.28	63	-230	±49.0	0.07	25
	1.38	63	-94	±8.7	0.22	15

Table 7. Triboelectric charging conditions selected for different ordered mixes containing potassium chloride as a model drug.

Powder sample Carrier excipient	Drug content, %	Flow rate (g s <sup>-1</sup> )	Air pressure (mm)
Dipac	0.5	5.1	63
Recrystallized lactose (710–100) μm size fraction)	0.5	0.88	63
Dipac	10	5.1	63
Emdex	10	0.22	63
Recrystallized lactose (250–500) μm size fraction)	10	0.20	63

drug and excipient particles will facilitate close contact between the particles, thus increasing the cohesion in ordered units. The resulting interaction of surface forces such as Coulomb forces, dipole forces and molecular forces described by Cross (1975), will increase the stability of the ordered units. Molecular forces include van der Waals interactions which vary with separation distance according to the inverse 7th power over distances less than 20 nm and the inverse 8th power over larger distances. Thus, the strength of the van der Waals forces between two macroscopic bodies depends critically on the true contact area between them. Increased electrostatic attraction could bring two particles into closer apposition which, if less than 20 nm separation, would increase the van der Waals adhesion forces by a factor of 10. Additionally, Dahneke (1972) estimates that the true adhesion force would be increased by a factor of at least 20 for

materials with low Young's moduli, where surface flattening is produced. Harper (1967) suggested that on first contact a surface asperity could be represented mathematically by an approximation to a cone with its tip in contact with a plane surface. As soon as contact pressure is exerted the asperities deform plastically, forming small areas of true contact. The electrostatic forces described above, particularly Coulomb forces, may be instrumental in producing this initial plastic deformation which brings the drug and excipient particles into closer contact. Once this contact is established the ordered units benefit from increased van der Waals forces.

### Conclusions

Contact and frictional electrification can be used to develop surface charges on drug and excipient powders. These surface charges can be optimized to facilitate the formation of ordered mixes and to minimize their segregation tendency.

When tested after pouring off a glass substrate, most drugs and excipients charged negatively whereas when placed in contact with a polyethylene surface many of the same powders were charged positively.

Triboelectrification in a brass cyclone produced charges on Emdex and recrystallized lactose particles that were opposite in sign to those on a model drug powder, potassium chloride. These drug-excipient combinations formed stable ordered mixes. Conversely Dipac, for example, which formed unstable ordered mixes with the same model drug, developed an electronegative charge comparable with that of the potassium chloride.

Table 8. Segregation tendencies of different ordered mixes subjected to various vibration conditions with and without prior triboelectrification. (Coefficient of variation = CV).

	Vibration frequency (Hz)	Vibration acceleration (G)	Without charging		With triboelectric charging	
			(CV%)	Error Limits	CV(%)	Error Limits
Dipac and 0.5% potassium chloride	50	2.25	61.48	±28.3%	6.9	±1.4%
Recrystallized lactose (710–1000 μm size fraction) and 0.5% potassium chloride	50	2.25	19.57	±5.5%	3.9	±0.85%
	30	2.25	21.15	±13.5%	13.2	±1.8%
Dipac and 10% potassium chloride	50	0.75	—	—	3.1	—
	50	2.25	500.1	±175.6%	17.9	±1.95%
Emdex and 10% potassium chloride	50	2.25	118.9	±4.5%	7.4	±1.4%
Recrystallized lactose (250–500 μm size fraction) and 5% potassium chloride	50	2.25	93.2	±0.2%	13.5	±3.3%

The dependence of ordered mix stability on the triboelectric properties of the surface with which the powders are contacted has important practical implications. For example, if during scale-up of a pharmaceutical process the construction material is changed from say, plastic to metal the properties of the mix being processed may be adversely affected; thus, a mix which during development was considered to be non-segregating may become destabilized.

The addition of a third component such as magnesium stearate may also reduce the stability of a two-component ordered mix due to electrostatic charge interactions.

Triboelectrification increased the charge on various drug and excipient powders by a factor of at least 100 compared with the same materials charged by contact with a glass surface. The triboelectrification conditions in a brass cyclone were found to affect the specific charges on different powders. Reducing the air pressure at a given powder feed rate increased the electrostatic charge by prolonging powder residence in the cyclone and ensuring longer contact times between particles and the cyclone wall. A reduction in feed rate at constant air pressure further increased the electrostatic charge by achieving more intimate contact between particles and the cyclone wall.

By selecting conditions of triboelectrification to produce the optimum interparticle attraction between drug and excipient particles the segregation resistance of unstable ordered mixes can be enhanced. Triboelectrification is thought to improve the stability of ordered mixes by facilitating close surface contact between drug and excipient particles as a result of Coulomb forces, thereby increasing the interparticle adhesion due to van der Waals forces.

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