A Century of Development in Applied Electrostatics;

Nothing Static Here!

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Topics

- Background
- What is Electrostatics?
- Particle Charging
- Three Important Developments 20th Century:

  1) Electrostatic Precipitation (ESP); 1907

  2) Electrostatic Painting ;1930's

  3) Electrophotography (Xerography) ; 1950-59

- The 21st Century

In the beginning; there was LIGHTNING

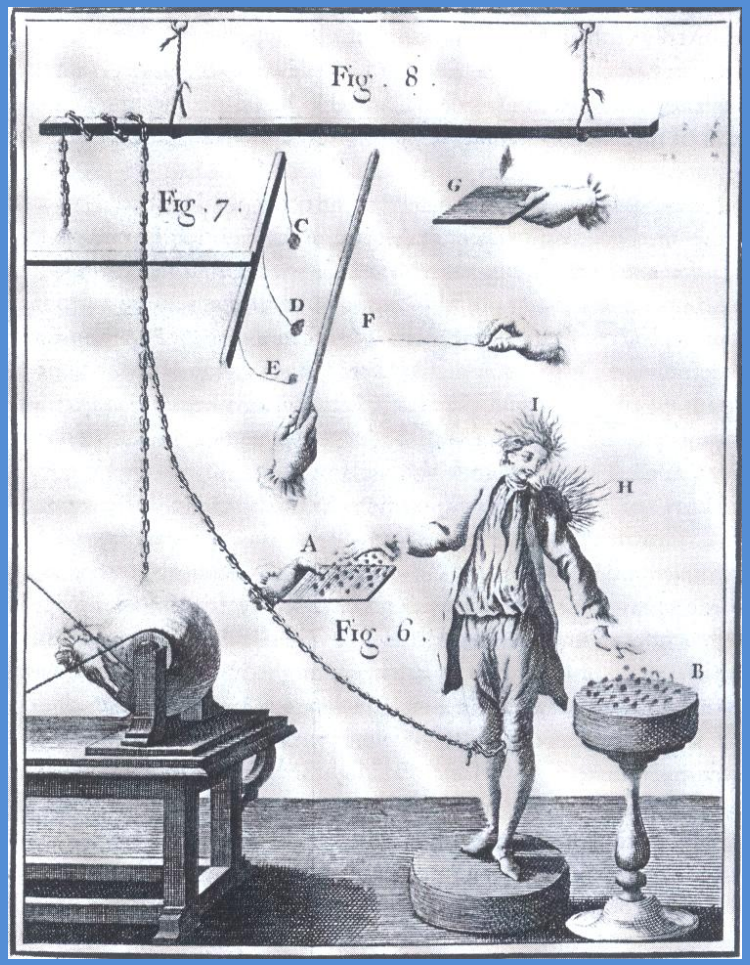
Atmospheric

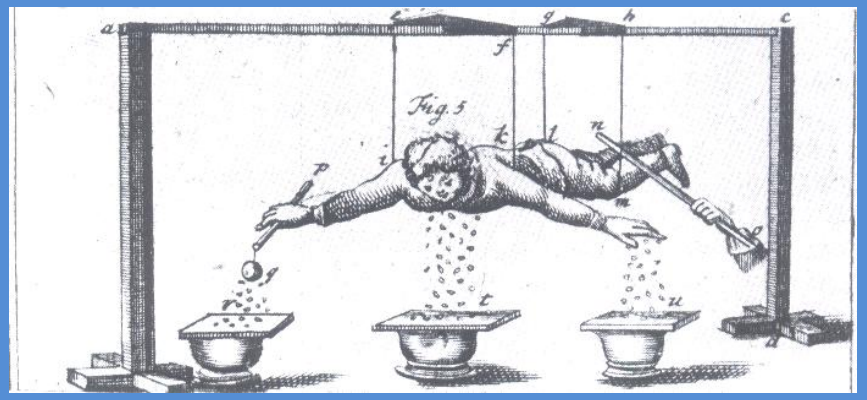
Volcanic

Thales of Greece 624-536 BC

- Philosopher and “Father of Science”
- Showed **magnetic** force (lodestone)
- Showed **electrostatic** force (amber/fur)
- Amber in Greek aka “**elektron**”

Last 2400 + years
Regarded as a scientific curiosity





Or a force of “tingling” attraction

Or a Shocking Experience

Fast Forward

- Majority of us repeated Thales experiment in grade and/or high school (with varying degrees of success)
- Regarded as a quaint scientific curiosity
- Science of electrostatics

  generally ignored in university

Engineering Reality

- **Electrostatic processes** are basis of many important applications
- **Diverse fields**;

  air pollution control, printing and copying, painting, materials separation, sand paper manufacture etc.
- All came to fruition in the **20th century**
- Common feature; involve controlled movement of **small particles** (mm to nm)

Why?

1) Compared to **gravity**, electrostatic Coulomb force dominant for small particles

Charge to mass ratio (Q/M)

$Q \alpha$ surface area αr^2

$M \alpha$ volume αr^3

$$\mathbf{Q/M \alpha 1/r}$$

2) Energy **efficient**

3) **Direction** and **strength** of force controllable by E

What is Electrostatics?

Is it really “static”?

- Cannot be; otherwise no work is possible
- Unfortunately IEEE definition is misleading;

“the branch of science that treats of the electric phenomena associated with electric charges ***at rest*** in the frame of reference”

Formation of "Electrostatics Society of America" in 1970

- ESA definition;

"the class of phenomena recognized by the presence of electrical charges, ***either stationary or moving***, and the interaction of these charges, this interaction being ***solely by reason of the charges and their positions and not by reason of their motion***"

- In practical application means **electric field** effects **predominate** over **magnetic field** effects
- In electric circuit terms, ratio of voltage to current is very high i.e. **high impedance**

Also should refute common misconception; need high voltage

- F =QE but E is the gradient of voltage and so depends upon geometry
- Consider a common reference field, the **breakdown strength of air**

  3 MV/m = 30 kV/cm = 3 V/µm

Key to practical applications in the 20th century?

Reliable **charging** and **power supplies**

- **Ionic charging**; corona discharge

  useful for any material
- **Induction (conduction) charging**; field induced

  only works for conductive materials
- **Contact (triboelectric) charging**; dissimilar materials

  occurs in all materials but only practical for cases where at least one is an insulator

Three Important Developments;

1) Electrostatic Precipitation (ESP)

- **Charge** particles in air stream using corona discharge
- **Collect** on grounded plate through Coulombic attraction

    -Very **simple** in concept

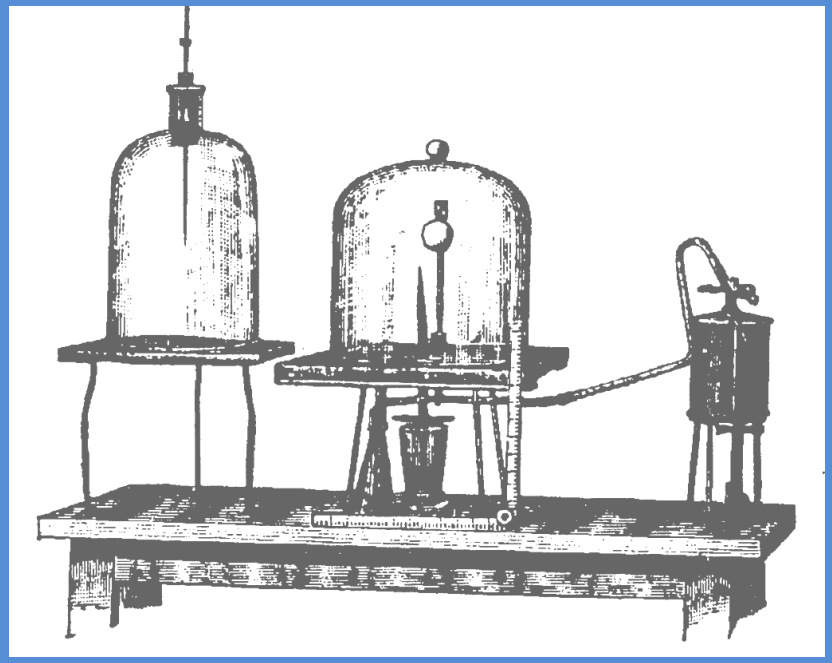
    -**Difficult** to translate into practice

    -**Interdisciplinary** problem; complex interaction among electrical, mechanical and chemical properties

Evolution

- Hohlfield (Germany) 1824

  -used corona to clear fog in a bell jar



Evolution

- O.J. Lodge (U.K.) 1885

-patented process, demonstrated successfully in lab

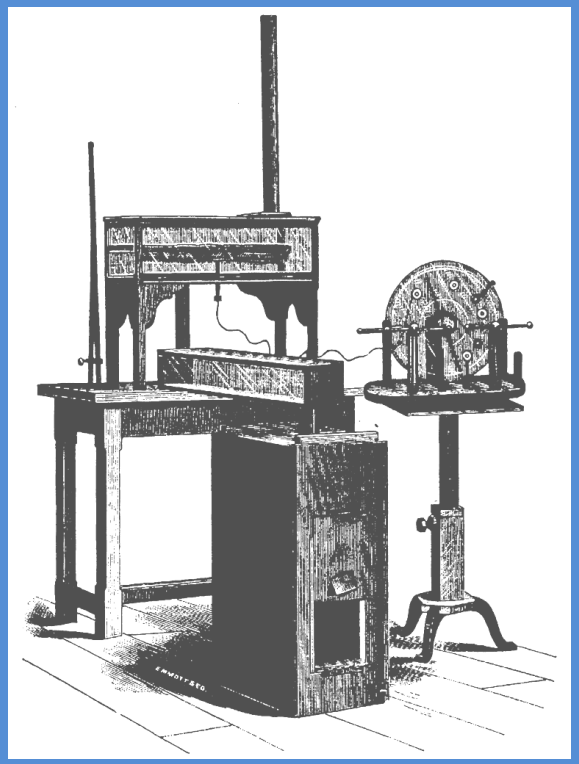
-installed at a smelter in North Wales

-failed to work!

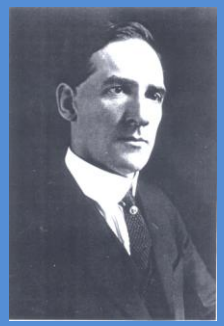
TWO Reasons;

a) inadequate power supply

b) lead oxide fume



F.G. Cottrell



- 1st successful installation at sulphuric acid plant south of S.F. in 1907
- Breakthrough due to four factors

-mechanical rectifier

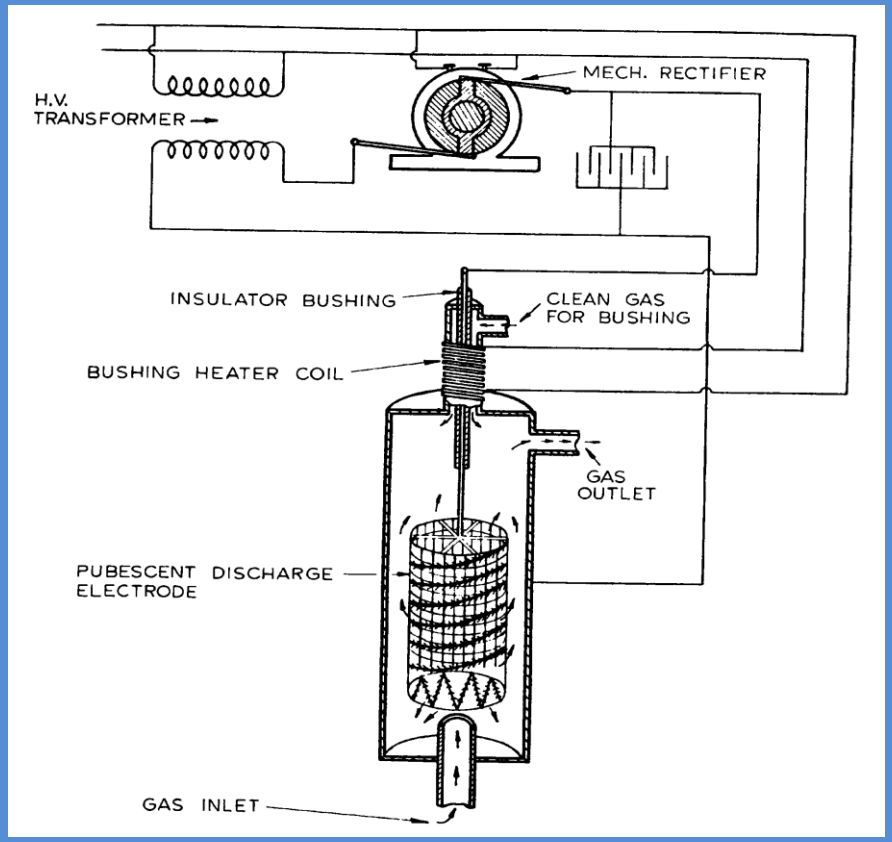
-"pubescent "corona electrode

-negative corona

-heated HV bushing

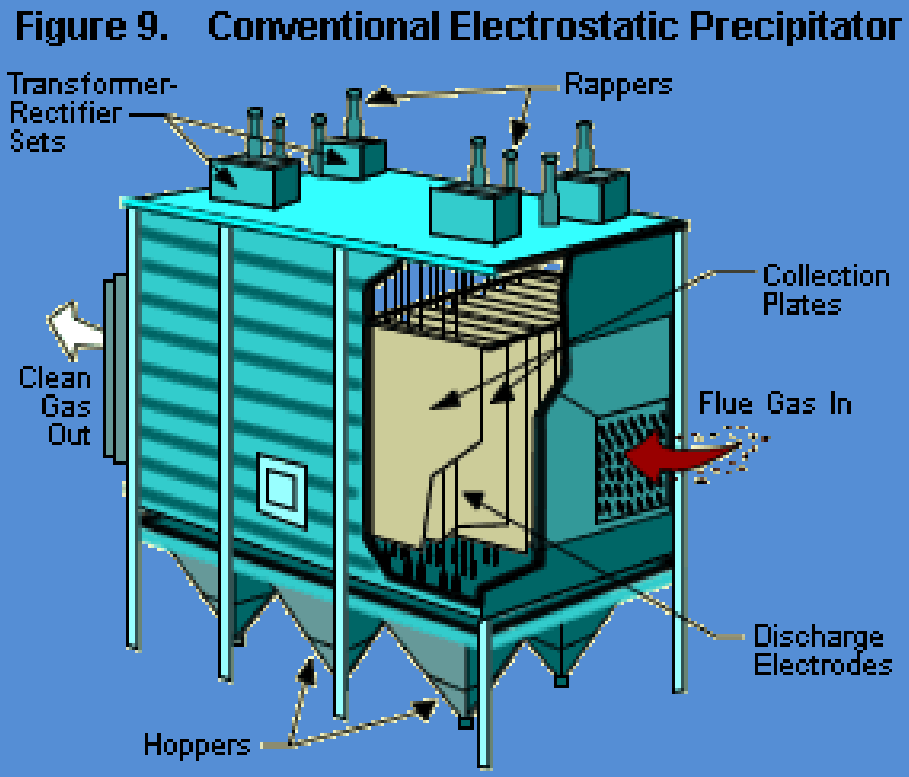
Also lucky; sulphuric acid mist

Patent 1908



Preferred method for cleaning large scale industrial particulate emissions

- By 1960's η > 99% (wt)
- Currently η > 99.9% (wt) and limits on escaping particles < 10 µm
- Improvements; gas conditioning, corona wire geometry, power supplies, pre-charging, rapping optimization, intermittent and pulse energization



Current Challenges

- Improve collection for sub-micron particles
- Remove gaseous pollutants along with particles

  -non-thermal discharge plasmas

  -electron beam reactors

  -advanced oxidation techniques
- Issue of effectiveness and energy efficiency

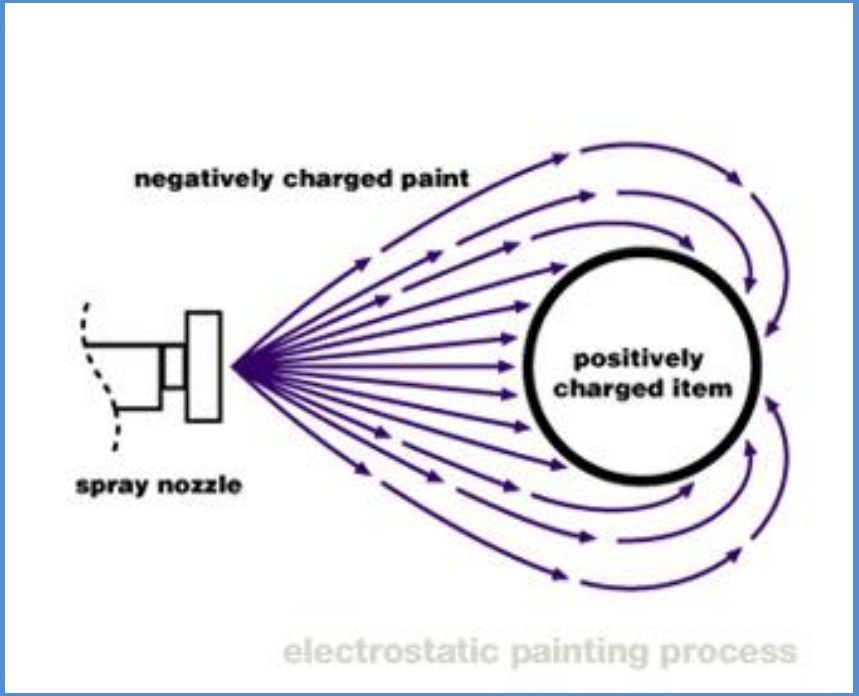
Three Important Developments;

2) Electrostatic Painting and Coating

- In 1930's liquid, mechanical atomized **spray painting** developed
- Ease of application but η =**30%** common
- Recognition that principle of ESP could improve η
- By 1940's automated painting lines regularly achieved η > **70%**

Liquid Electrostatic Paint Spraying

- Improved **uniformity** of coating (space charge) and "**wrap around**" (Coulomb attraction)
- Led to **improvements** in atomizers; blade, rotating bell or disc and hydraulic or air; robotic control etc

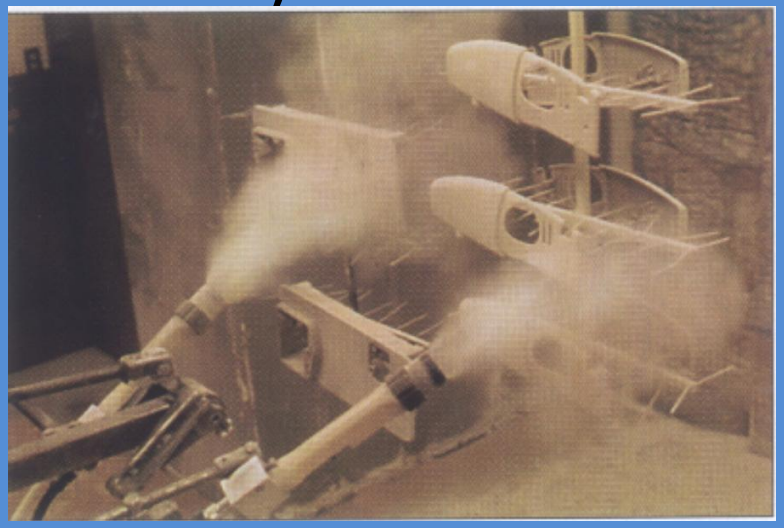


Led to Powder Coating

- 1960's, recognized that **solvent not necessary**
- Spray paint in form of finely dispersed, electrically insulating, thermoplastic **powder**
- **Charge** (corona or triboelelectric)
- Paint **attracted** to target,

  adheres (image force)

  fused in oven



Key advantage; no (VOC) Volatile Organic Compounds

- Widely adopted starting in 1970's
- Led to major improvements in

  a) equipment

  b) powder formulations (electrical and chemical properties)

Features of Powder Coating

- Note electrostatic force is essential to operation
- Currently η >**80%** and overall η >**95%** by recycling overspray
- Surface quality and uniformity still needs work

Three Important Developments;

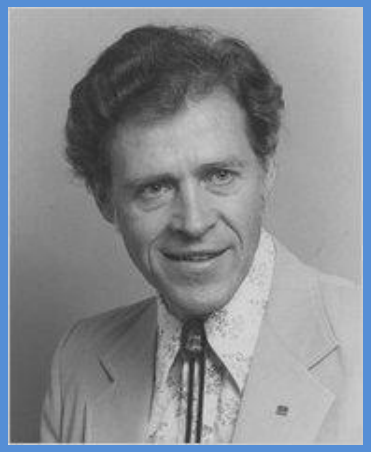
3)Electrophotography (Xerography)

- ESP and liquid painting **significant** improvements in technology
- Powder coating (and elimination of solvent) a **major** improvement in technology
- Demonstration of first electrophotographic image by Chester Carlson in 1938, truly a **revolutionary** development

Chester Carlson

- Initially worked from his "kitchen" laboratory
- First to make true dry copies of documents

Bob Gundlach (1926-2010)



Six Step Process

Most complex combination of electrostatic processes;

-photoconductivity

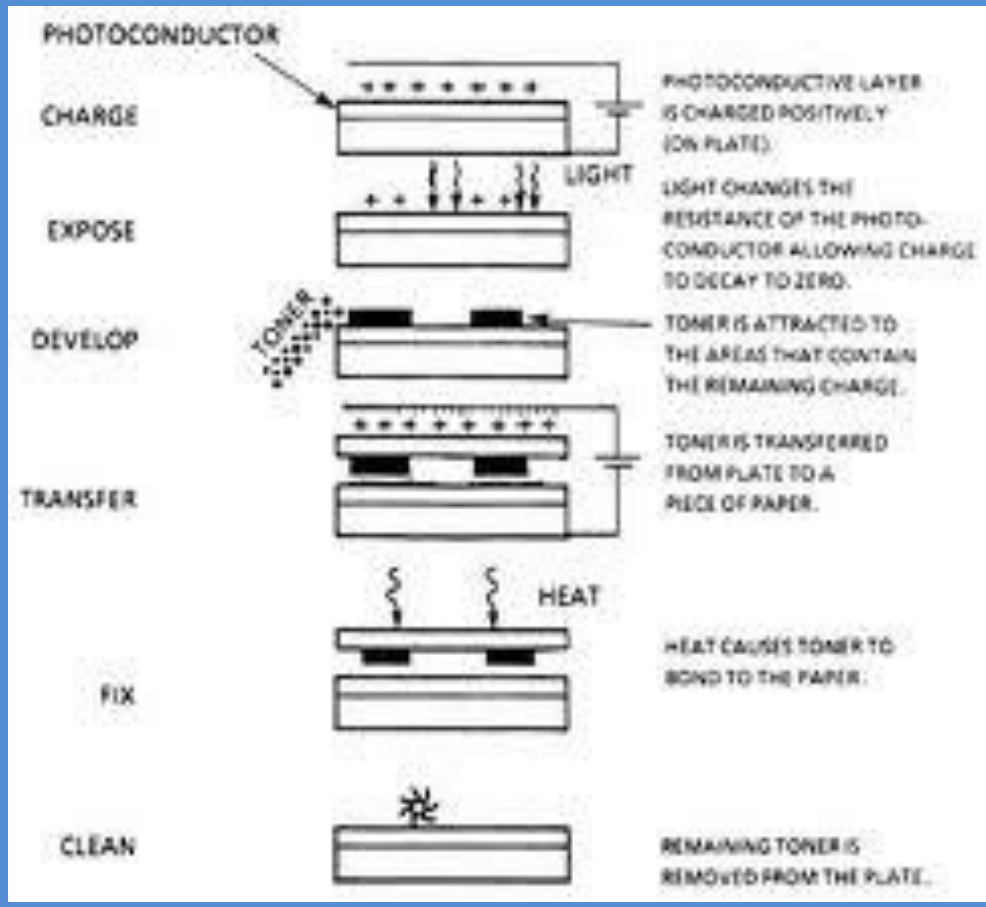
-corona charging

-triboelectric charging

-coulombic attraction

-image force adhesion

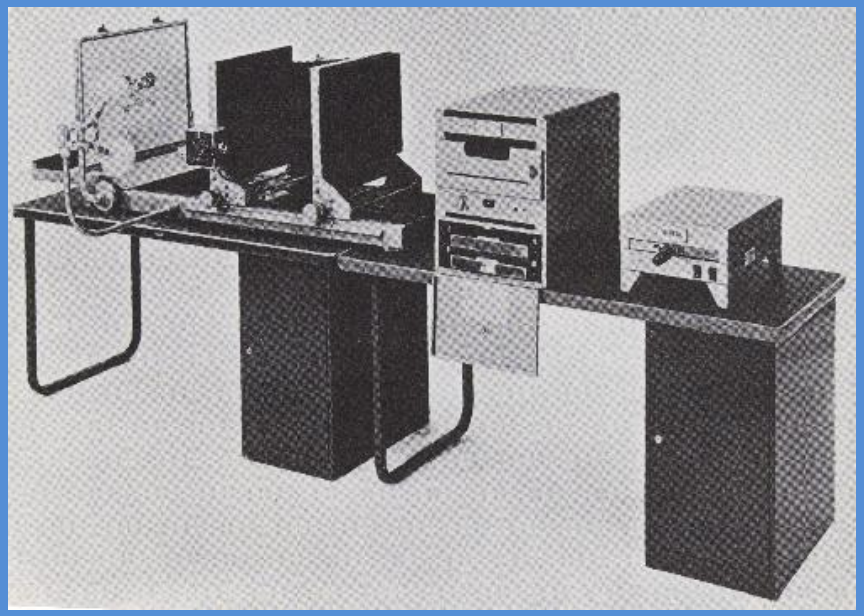
-ionic neutralization



Early Machines

Model A (1949)

3 minute/copy



XEROX 914 (1959)

26 sec/copy

Commercialization

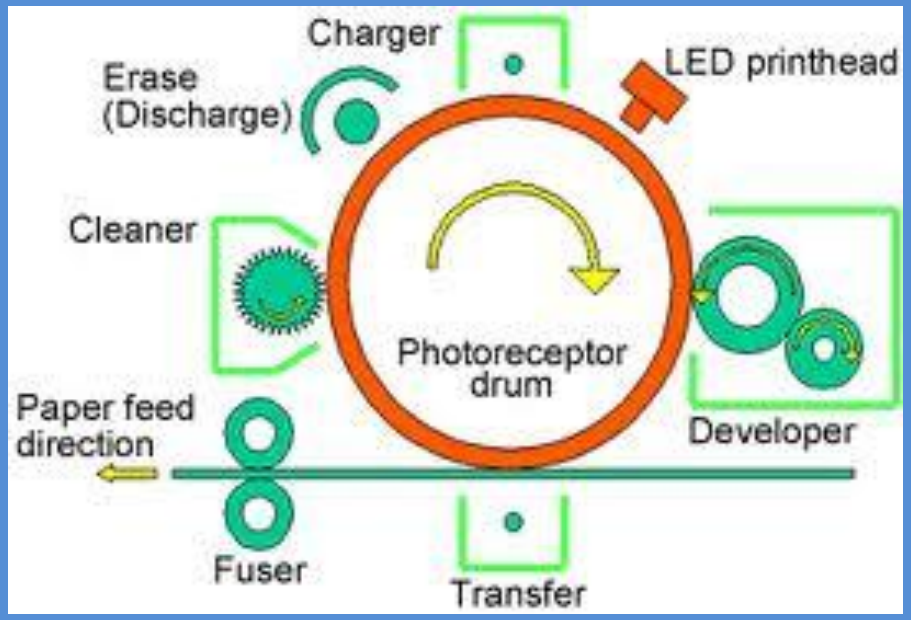
- 1959; Xerox 914 first black and white plain paper copier
- 1973; first printer with flash lamp exposure
- 1975; first laser printer (IBM)
- With competition, developments "exploded" in 1980's and 90's;

  -full colour copiers/printers;

  -many billions of dollars of commerce

  -revolutionized business/home offices

  -desktop publishing



Lesson in all this?

- Don’t forget “old” science
- Reliability of good image production is dependent upon consistent **tribocharging**
- Thank you Thales!

NEW APPLICATIONS?
21st Century

Look to three main characteristics

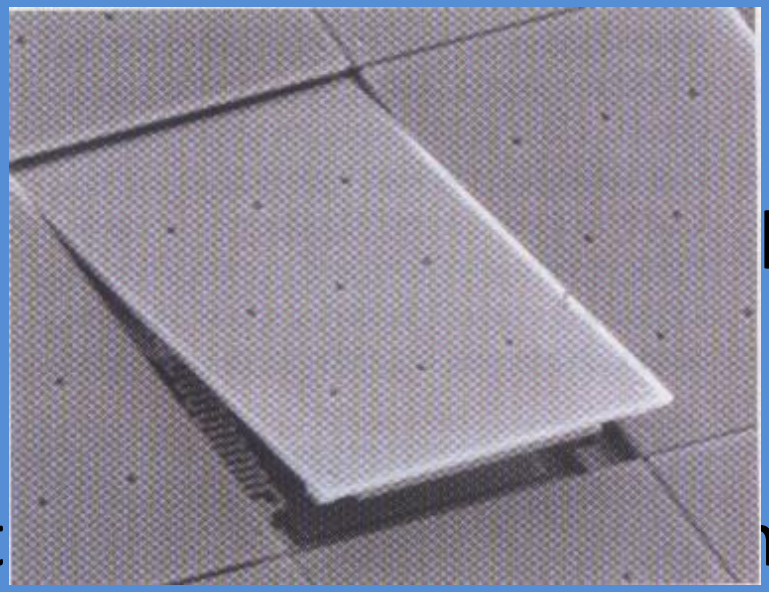
1) useful for particles from **submicron to millimetre size**

2) force **increases** as distances get **smaller**

3) energy **efficient**

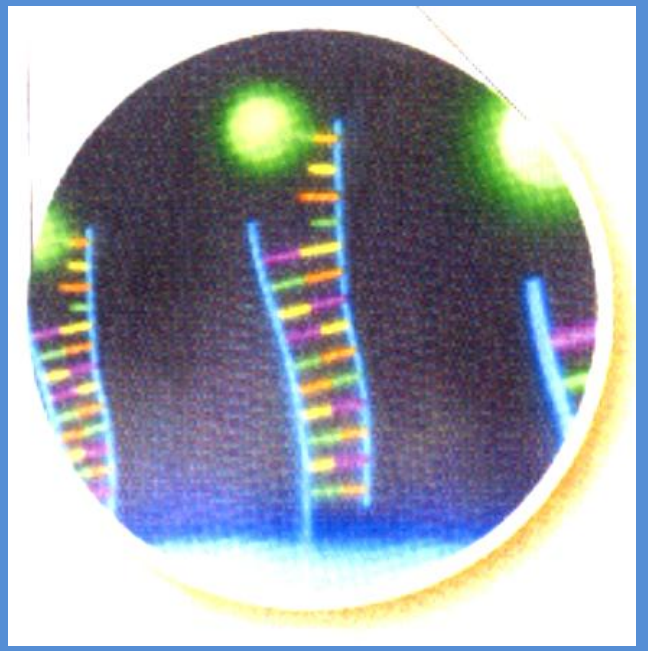
MEMS
(Micro-Electrical Mechanical Systems)

- Revolutionary devices; comparable to effect microprocessors had on computers
- Mass produce integrated sensors, actuators etc
- Interface between computational and world
- Fabrication and operation dependent electrostatic forces



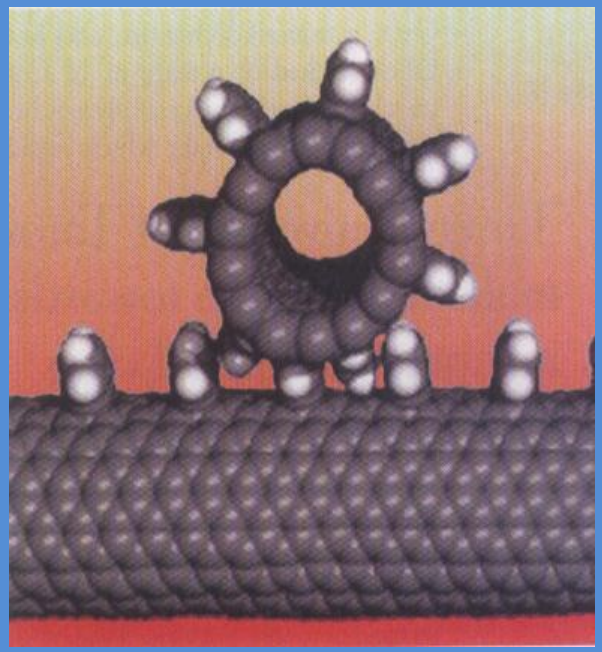
Biotechnology

- Many biological processes governed by electrostatic factors
- Wide application for electrophoretic and dielectrophoretic forces



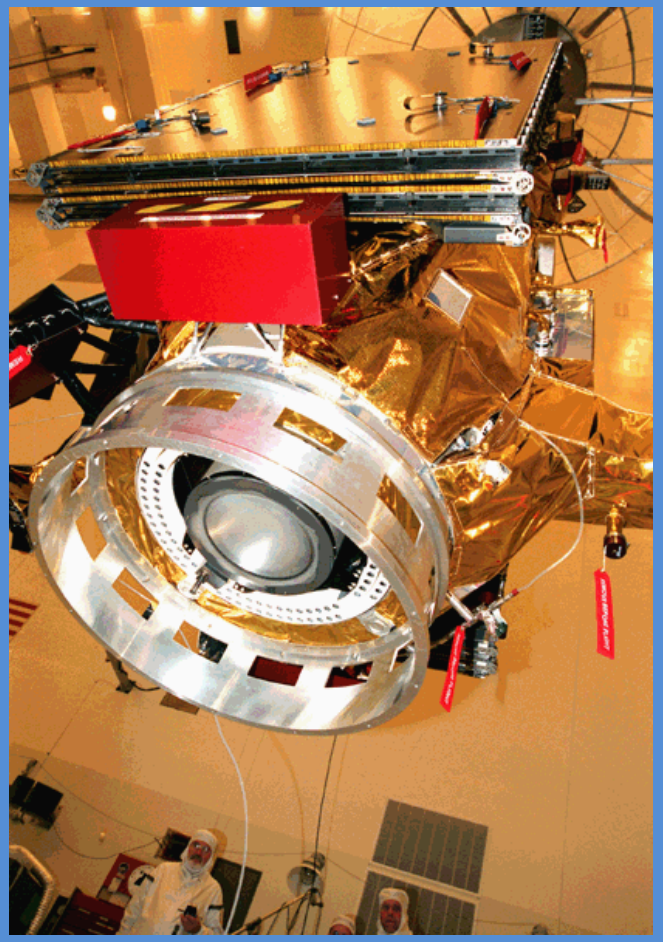
Ultrafine Particles and Nanotechnology

- Nanometer sized particles finding increasing application in industry
- Characterized by high surface energy which greatly affect properties of ceramics, metals, optical structures and semiconductors
- Fabrications being pushed to atomic dimensions



Space

- Absence of gravity and presence of vacuum allows upper and lower size range of particles to be extended
- “Deep Space I” spacecraft



Thank you very much

Important Characteristic

- In ESP electrostatic force; **basis of process**
- In liquid painting electrostatic force **improves** the process and enhances η and uniformity
- If voltage fails, process still works