Electrical characteristics of fibers

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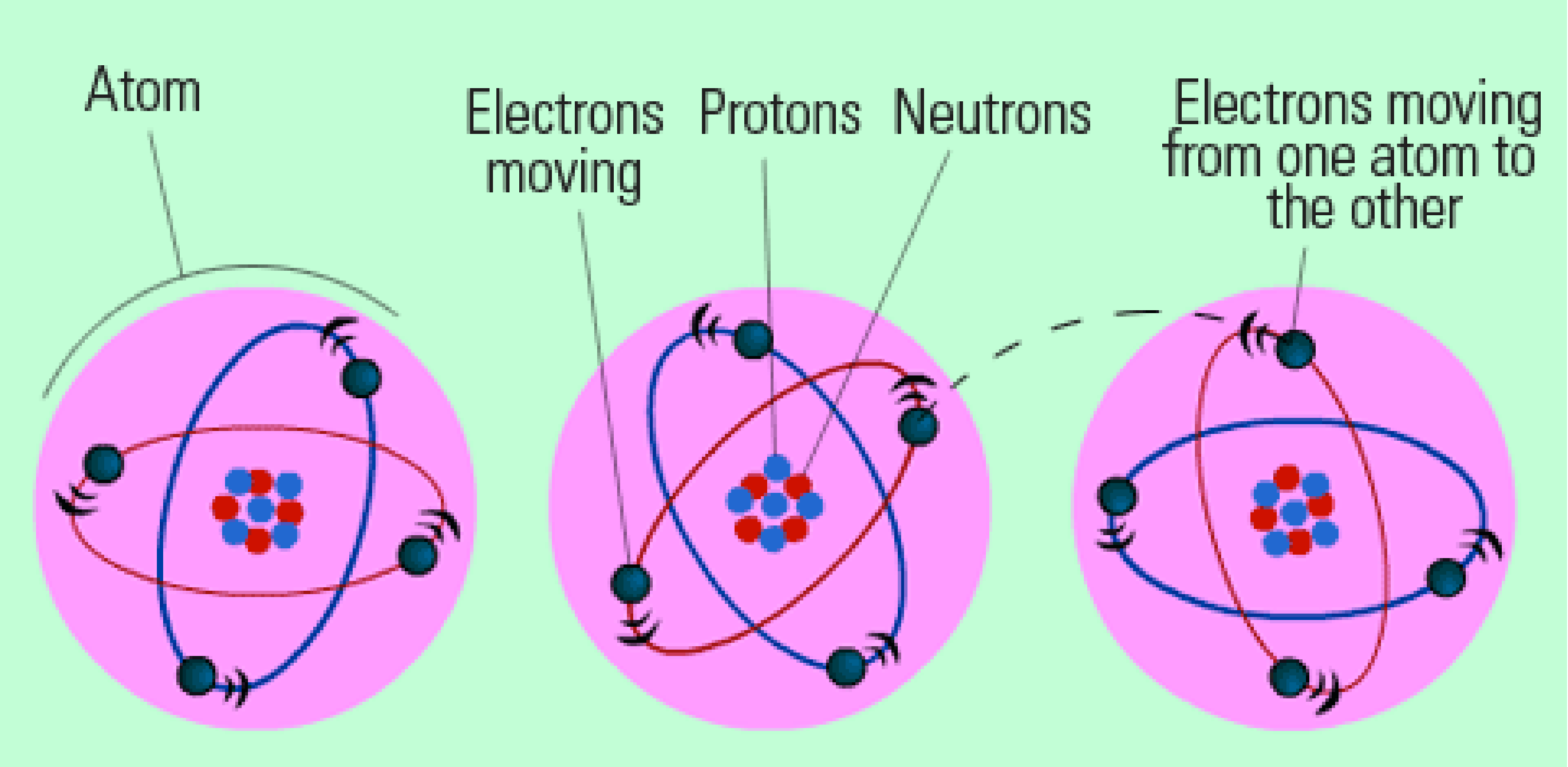
Electrical energy

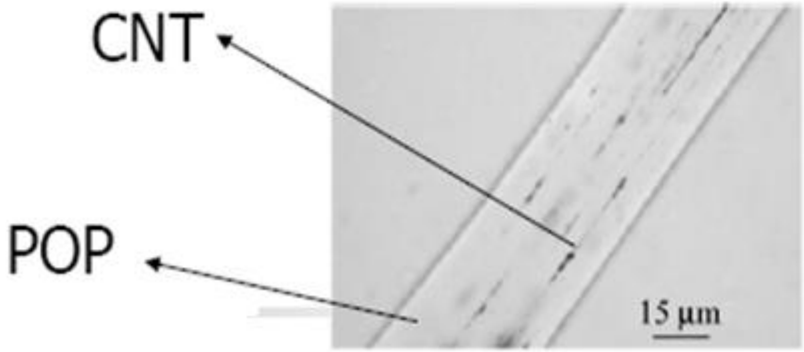


Electric properties

Response of materials in electric field :

- Transport of electrically charged particles i.e. arising of electric current accompanying by energy dissipation, typical for conductors.
- Originating of dipoles and induced dipoles accompanying by energy accumulation. This process is reversible and typical for insulators. (dielectrics).

Electric behavior of Fibers



- Majority of textile fibers are electric insulators, because all electrons are linked to the atomic nucleus or shared in covalent bonds.
- Electrical conductivity is not equal to zero but is dependent on contents of various impurities and water content.
- Hydrophilic fibers electrical conductivity can be increased about 8–10 order due to presence of 1% of moisture.

Conductivity of various Materials

Conductivity is product of charge carriers concentration n [mol·m^{-3}] charge magnitude q [C·mol^{-1}] and charge carriers mobility u_p [m^{2}V^{-1}s^{-1}].

For systems with more charge carriers is valid

$$\sigma_E = \sum n_i * q_i * u_{pi}$$

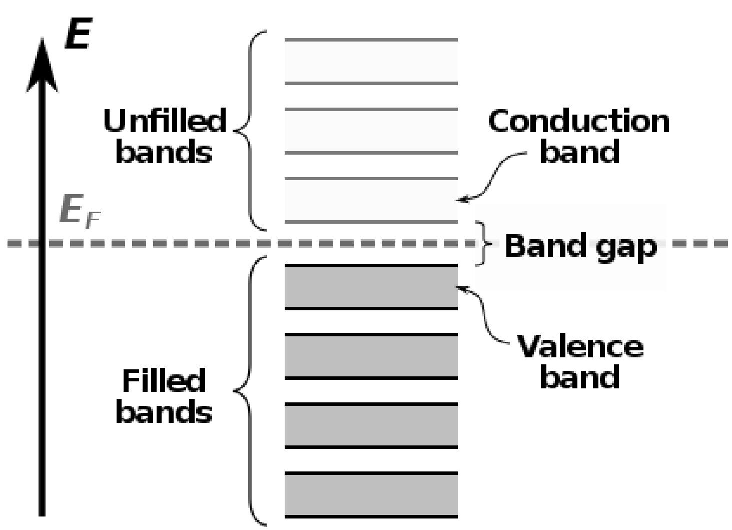
material	n [mol.m^{-3}]	u_p [m^{2}V^{-1}s^{-1}]
metal	$10^3 - 10^4$	$10^{-3} - 10^3$
ceramic	$10^{-4} - 10^{-2}$	$10^{-3} - 10^{-3}$
organic semi conductor	$10^{-9} - 10^3$	$10^{-10} - 10^{-2}$

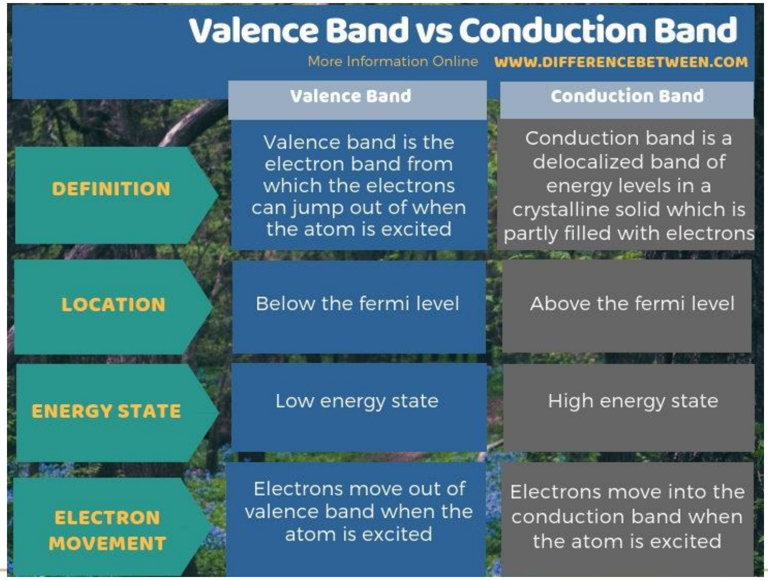
Electric Conductivity

- The outermost shell of electrons in a material contains the valence electrons.
- In order for conduction to occur, an electron must obtain sufficient energy to promote it to the conduction band.
- The energy difference between the valence band and the conduction band is known as the forbidden gap.
- For a conductor, the highest energy level of the valence band and the lowest energy level of the conduction band are similar, the forbidden gap does not exist and electrons pass easily into the conduction band.
- For an **insulator**, the separation between the two bands is large and promotion of an electron to the conduction band is not possible.
- With **semiconductors**, the forbidden gap is moderate and limited conduction occurs.

Band Theory of Conductivity

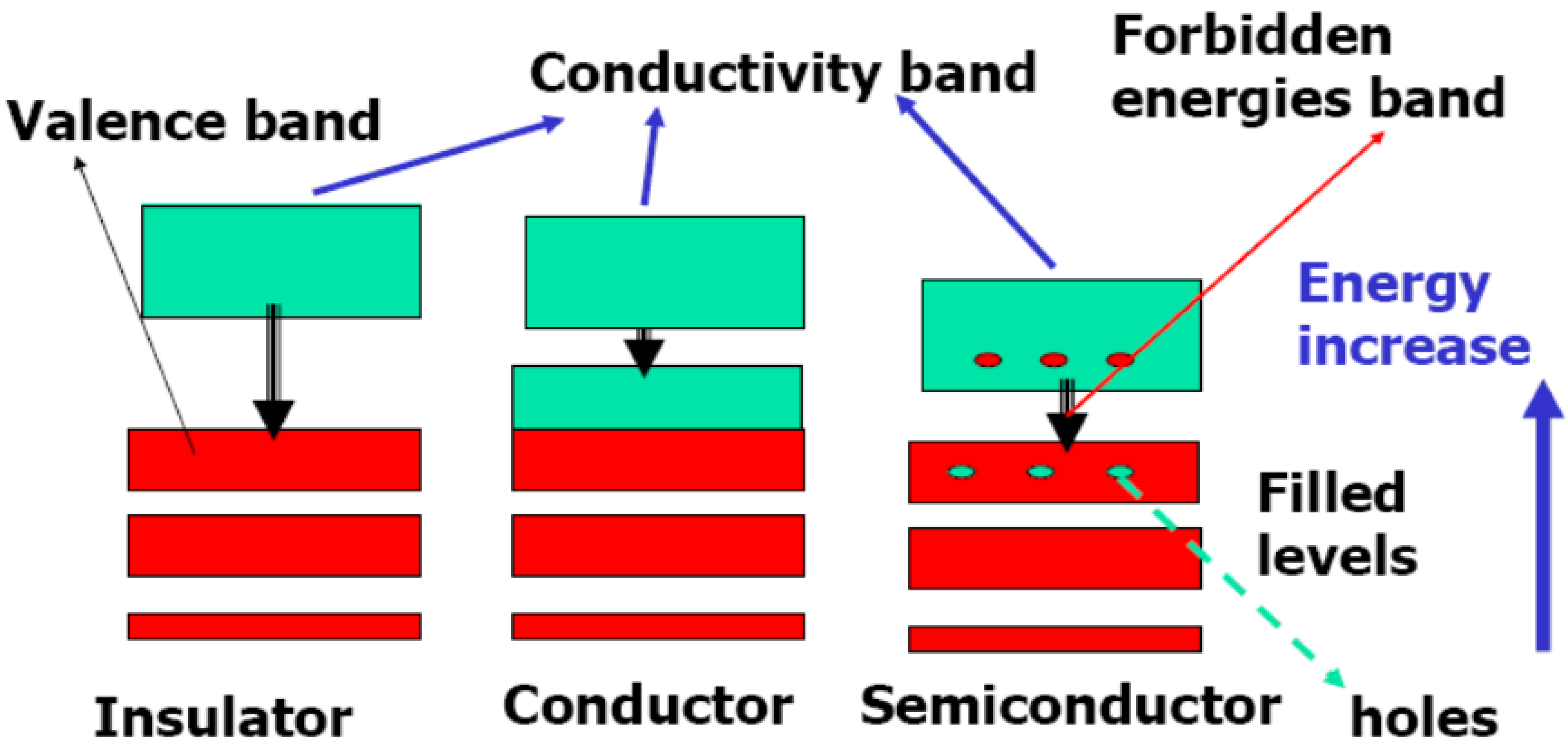
- Band – Collection of energy levels
- The collection of energy levels associated with the outer shell electrons (valence electrons) is called valence band. This is of utmost importance is determining the electrical and optical properties of the material. The valence band might be completely filled or half filled .It can never be empty.
- The collection of energy levels associated with the free electrons (since the free electrons are responsible for conduction they are called conduction electrons) is called conduction band. The extra energy required by a valence electron to move to the conduction band is called the forbidden energy.
- Depending on the magnitude of free energy we can characterize materials as metals, insulators and semi conductors.





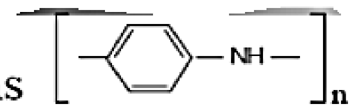
Band Theory of Conductivity

Solids: energies levels separated by forbidden energies bands

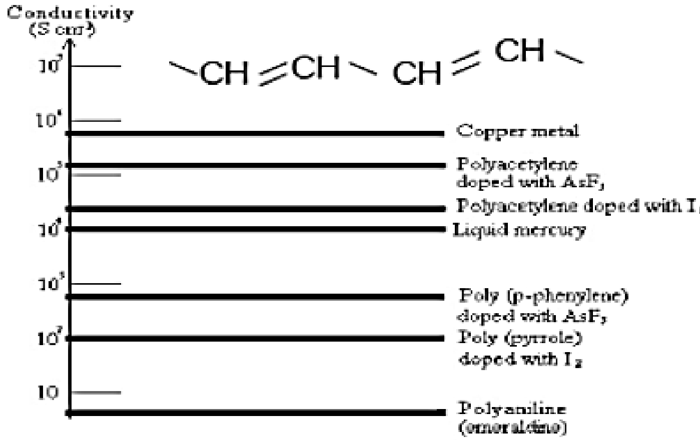


Hole and electrone conductivity

Conductivity of Polymers



- Charge carrier are ions and electrons. Conductivity is dependent on the jumps of electrons from valence band to the conductivity band through forbidden band. During the jumping are electrons falling into traps and are passing through traps by tunneling mechanism.
- Realization of jumps requires energy (e.g. heat). This jumping mechanism is typical for polymeric semiconductors having conjugate double bonds.



Logarithmic conductivity ladder locating some metals and conducting polymers

Temperature dependence of conductivity

Metals – conductivity is decreasing function of T

Semiconductors - conductivity is exponentially increasing function of T

Conductive polymers – increasing function of temperature (log conductivity is directly proportional to $T^{-1/4}$)

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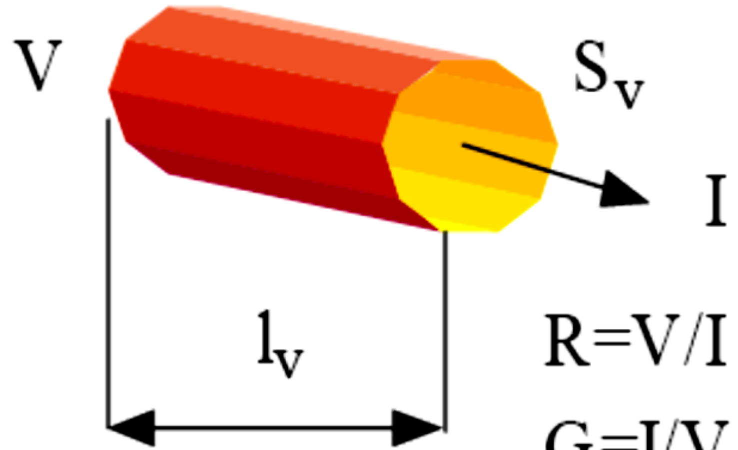
Electric Conductivity

- Voltage V [V]
- Current I [A]
- Resistance R [V/A]
- conduction G [S=A/V]

  [S] Siemens



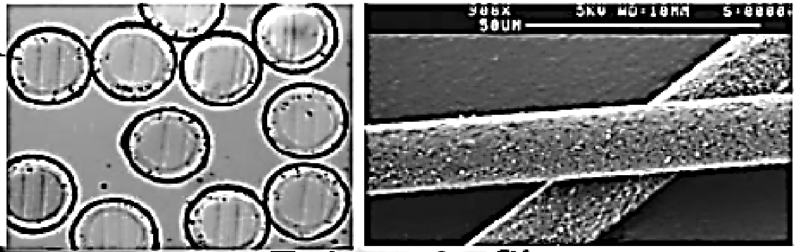
R=V/I

G=I/V

Fiber conductivity σ_E of length l_v and cross section area S_v is ratio of areal current density I/S_v and electric field intensity U/l_v

$$\sigma_E = \frac{I * l_V}{U * S_V} = \frac{G * l_V}{S_V} \quad [Sm^{-1}]$$

Electric Resistivity



- Electric resistivity is reciprocal value of electric conductivity

$$R_E = 1/\sigma_E \qquad [S^{-1}m = \Omega m]$$

conductors ($R_E = 10^{-8}$–10^{-2} Ω m),
semiconductors ($R_E = 10^{-2}$–10^{0} Ωm)
isolators ($R_E = 10^{0}$–10^{16} Ω m).
Common synthetic fibers $R = 10^{12}$–10^{14} Ω m.
Antistatic fibers $R = 10^{6}$–10^{10} Ω m.
Conductive fibers R about 10^{-5} Ω cm, or lower.
Electric resistivity of isolators and semiconductors is **decreasing** function of temperature. Electric resistivity of metals is **increasing** function of temperature !!

Electric Resistivity of Fibers

Relative electric resistivity R_E [Ωm] at 65 % RH and 20°C

Fiber	**CO**	**WO**	**CV**	**SE**	**PA6**	**PA6.6**	**PAN**	**PES**	**PP**
$\ln(R_E)$	5,6	7,3	5,8	8,7	13	11	14	17	12,5

Electrostatic charge and Electrostatic discharge

- **Electrostatic charges** are most commonly created by contact and separation; when two surfaces contact then separate, some atom electrons move from one surface to the other, causing an imbalance. One surface has a positive charge and one surface has a negative charge.
- **Electrostatic Discharge (ESD) -** If two items are at the same electrostatic charge or at equipotential, no discharge will occur. However, if two items are at different levels of ElectroStatic charge, they will want to come into balance. If they are in close enough proximity, there can be a rapid, spontaneous transfer of electrostatic charge. This is called discharge, or ElectroStatic Discharge (ESD).

Electrostatic charge - I

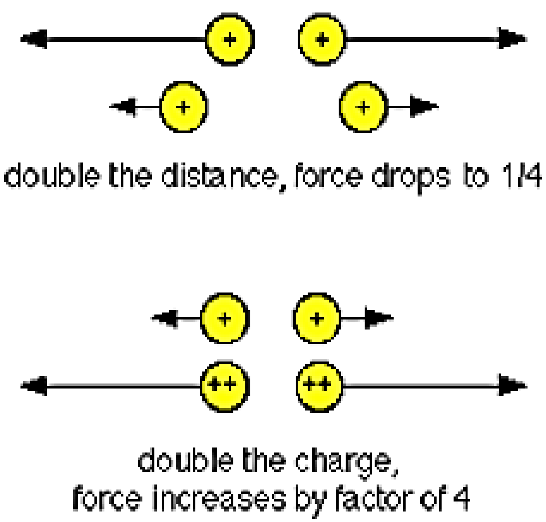
- Electrostatic charge is expressed in **Coulombs (C).**
- **Electron charge is -1.6 x 10 $^{-19}$ C**

Object with 6.25 x 10^{18} excessive electrons has charge of -1 C

Coulomb law

Force F between two objects with charges Q_1 and Q_2 at mutual distance d is

$$F = \frac{k * Q_1 * Q_2}{d^2}$$



Electrostatic charge - II

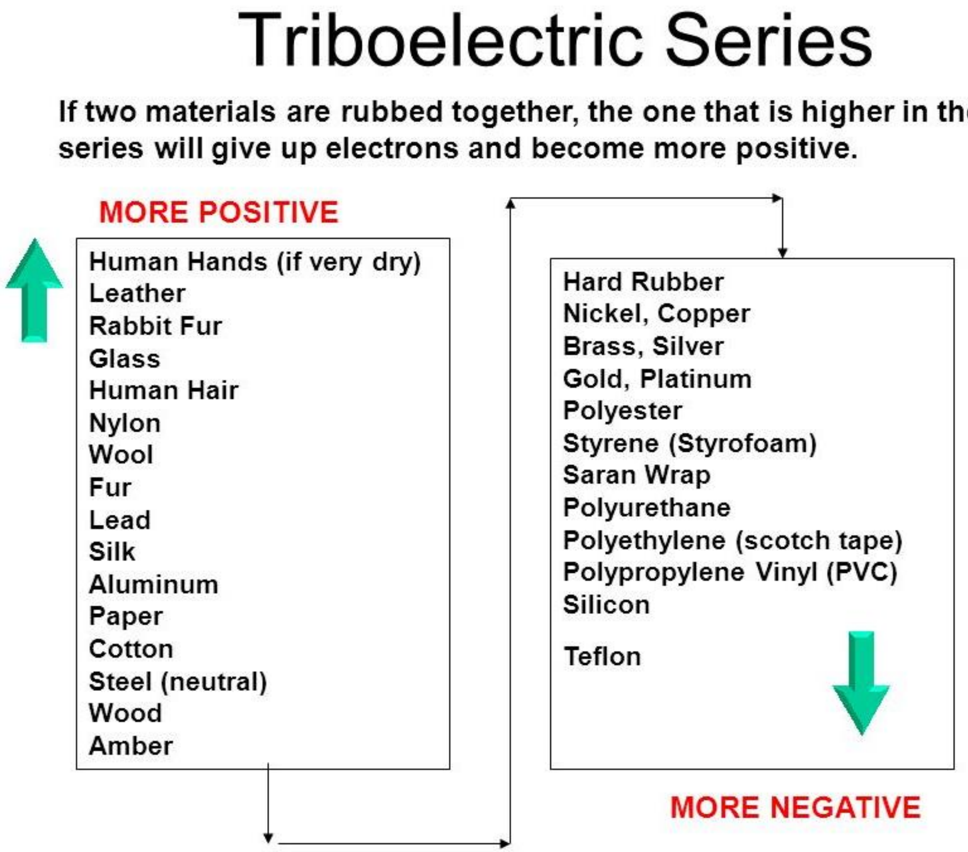
- Magnitude of electrostatic charge is directly proportional to the electric resistance of fibers.
- Electrostatic charge is responsible for „sticking" of various clothing parts and has negative influence on the textiles processing.
- Electrostatic charging requires redistribution of electrons or ions.
- Theoretical magnitude of electrostatic charge on fiber surfaces is up to 10^5 [μC/m^2]. Leaking to surroundings leads to lower value about 30 [μC/m^2]. Corresponding electric field has magnitude around 3000 [kV/m].

Origination of Charge

- When the fibers are in contact with metal, the free electrons cannot pass from metal but from fiber. This is due to the positive charge in fiber.
- When the fiber surface contains group of ionic nature (acid or basic nature), the redistribution of ions can occur during the contact with another fiber.
- When the number of moving ions is exponentially increasing the function of temperature.
- In the dependence on surface groups, the couple of various fibers are in mutual contact charged by opposite charge. The sign and strength of charge can be determined from so called triboelectric series.

Triboelectric Series

The **triboelectric series** is a list that ranks various materials according to their tendency to gain or lose electrons. It usually lists materials in order of decreasing tendency to charge positively(lose electrons), and increasing tendency to charge negatively (gain electrons).



Triboelectric Series

For more distant polymers, the stronger charge is created, Hersh and Montgomery

\+ wool
nylon
viscose
cotton
natural silk
acetate
PVA
polyester
PAN
polyethylene -
polytetrafluorethylene

Static Electricity Creation

Process of static electricity creation has three phases :

a) during contact between two bodies surfaces the movement of electric charge occurs and on the one surface is surplus of electrons.;

b) on the contact interface the electric double layer is created but due to mutual contact between bodies is system macroscopically electrically neutral;

c) After mechanic separation of bodies the static electricity occurs. This electricity is gradually decreased due to neutralization and dissipation (process is dependent on the bodies electrical resistance)

Static Electricity Effects

Static charge on the materials is responsible for these effects :

Static attraction — result is mutual sticking of textile layers, accumulation of dust on the fiber surface, soiling etc.;

Static repulsion — wrong adhesion at layering, coating, lamination and joining of several layers;

Static discharge — electric shocks at discharging through conductors, electric spark creation leading to combustion or explosion, damage of electronic devices, electronic smog appearance;

Physiological changes — increasing of blood pressure and blood pH, increasing of tiredness, decreasing of calcium content in urine.

Static Electricity Reduction

- Reduction of static charge generation can be obtained by: proper selection of materials, decreasing of mutual friction, decreasing of contact pressure and decreasing of mutual movements..
- Static charge transfer can be realized by: utilization of conductive materials or increasing of moisture absorption (hygroscopic material). Increasing of air moisture leads generally to removal of static charge.
- Static charge is neutralized by controlled movement of free ions in the vicinity of charged material. In the case of conductive fibers is charge neutralized by corona discharging.
- Electrostatic charge is blocked due to covering of charged body by conductive layer.