Ladning

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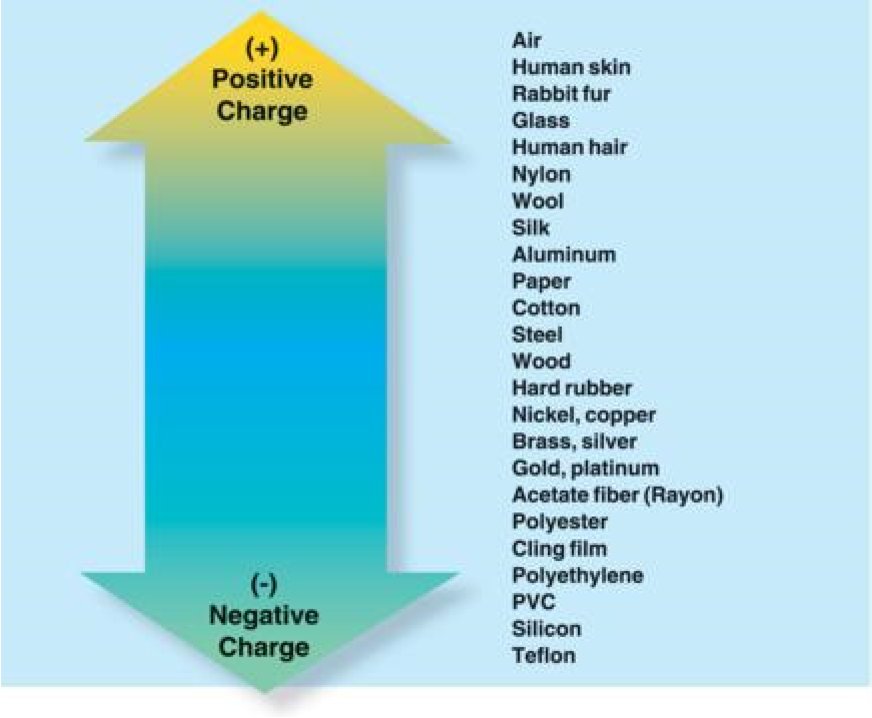
FRANKLIN'S EXPERIMENT, JUNE 1752.

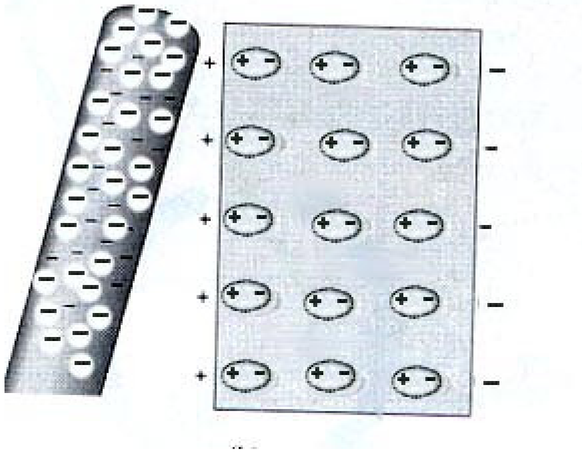
Demonstrating the identity of Lightning and Electricity, from which he invented the Lightning Rod.

Triboelektrisitet

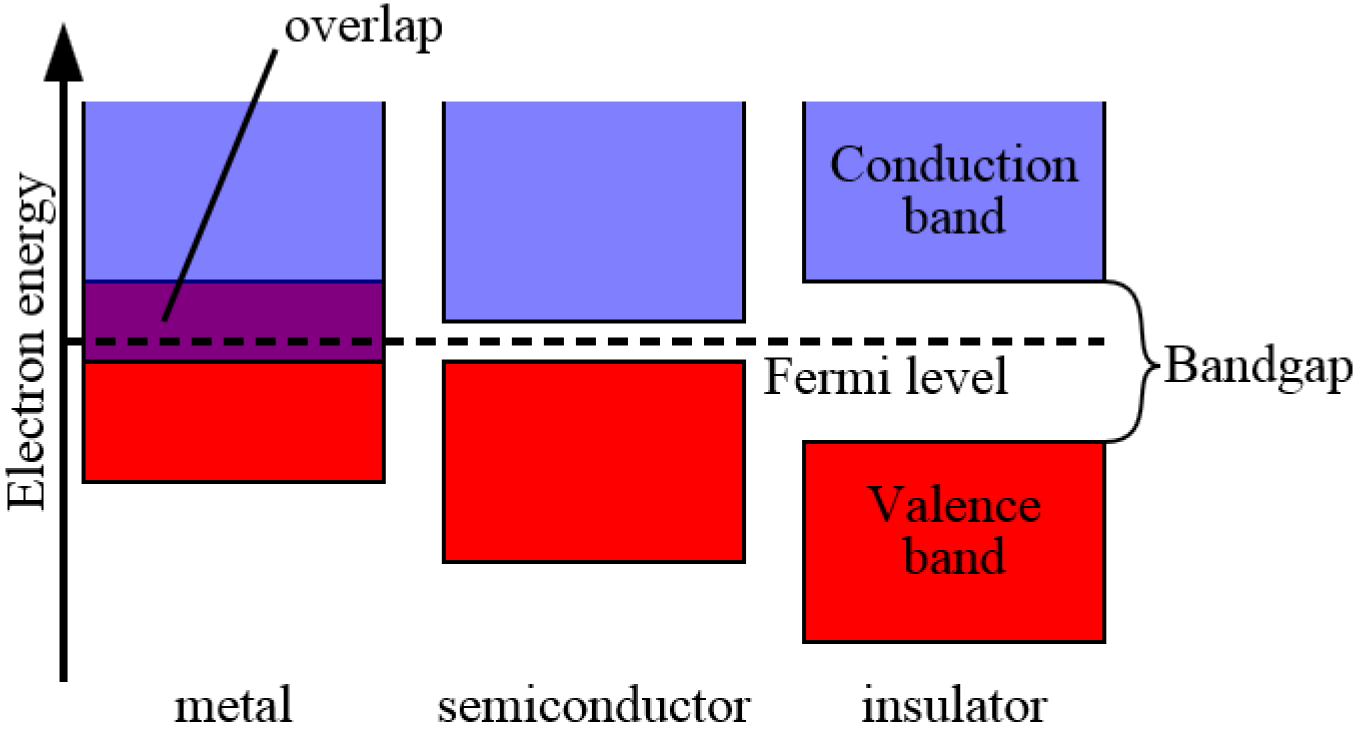


Air
Human skin
Rabbit fur
Glass
Human hair
Nylon
Wool
Silk
Aluminum
Paper
Cotton
Steel
Wood
Hard rubber
Nickel, copper
Brass, silver
Gold, platinum
Acetate fiber (Rayon)
Polyester
Cling film
Polyethylene
PVC
Silicon
Teflon

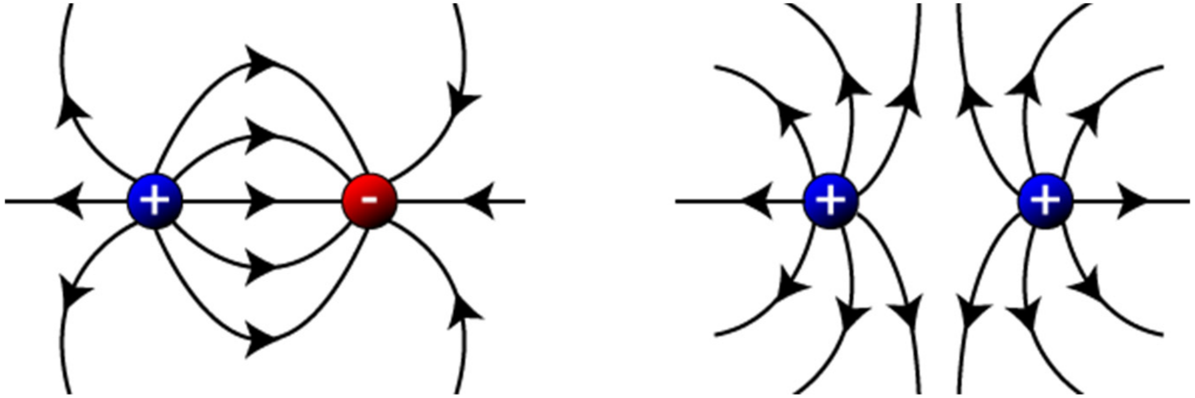
- Mekanisk omfordeling av ladning
- Påvirker bare få ladninger
- En kobbermynt inneholder nok ladninger til å drive en 100 W lyspære i 40 timer (Fraden)



Ladninger i faste stoffer



Elektriske felt



Elektrisk felt: $\boldsymbol{E} = \frac{\boldsymbol{F}}{q}$

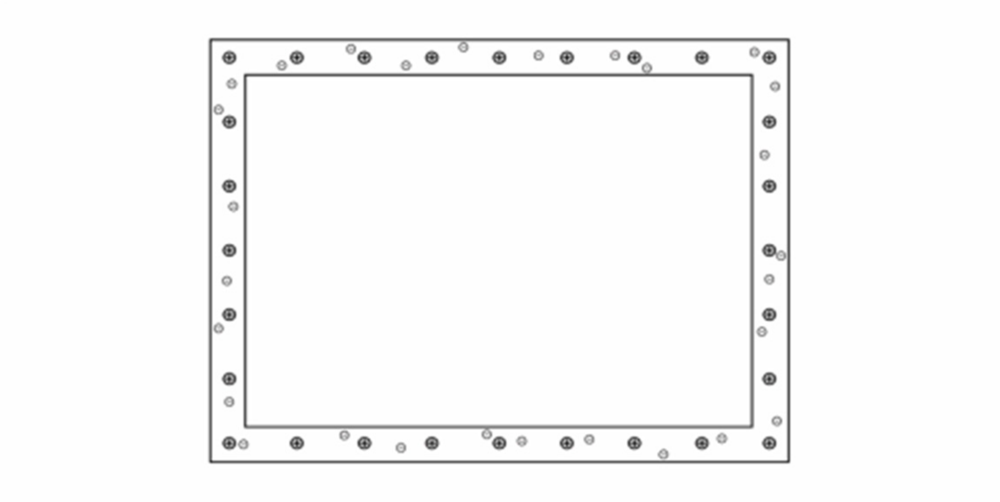
Gauss lov: $\Phi_E = \oint \boldsymbol{E} \cdot \boldsymbol{dA} = \frac{q_i}{\varepsilon_0}$

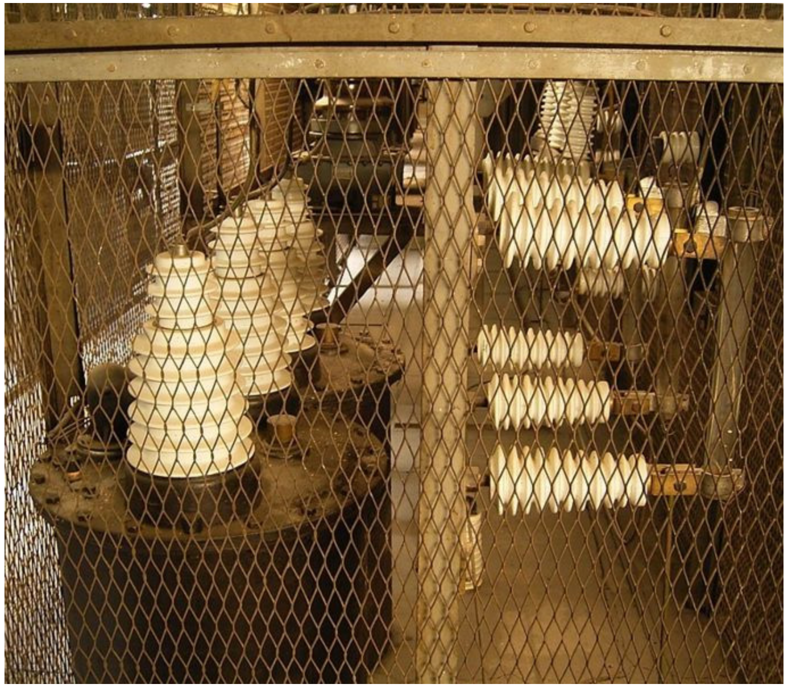
- Skalarfelt
- Vektorfelt

Faradaybur

(Michael Faraday 1836)

- Elektronene i metallet re-arrangeres slik at det ytre feltet nulles ut
- Holder feltet ute: Biler, fly
- Holder feltet inne: Heiser (mobiltelefoner), mikrobølge-ovner
- Hindrer ikke statiske eller LF magnetfelt
- Hindrer EM stråling hvis hullene er vesentlig mindre enn bølgelengden





Kilde: Wikipedia

Dipol i elektrisk felt

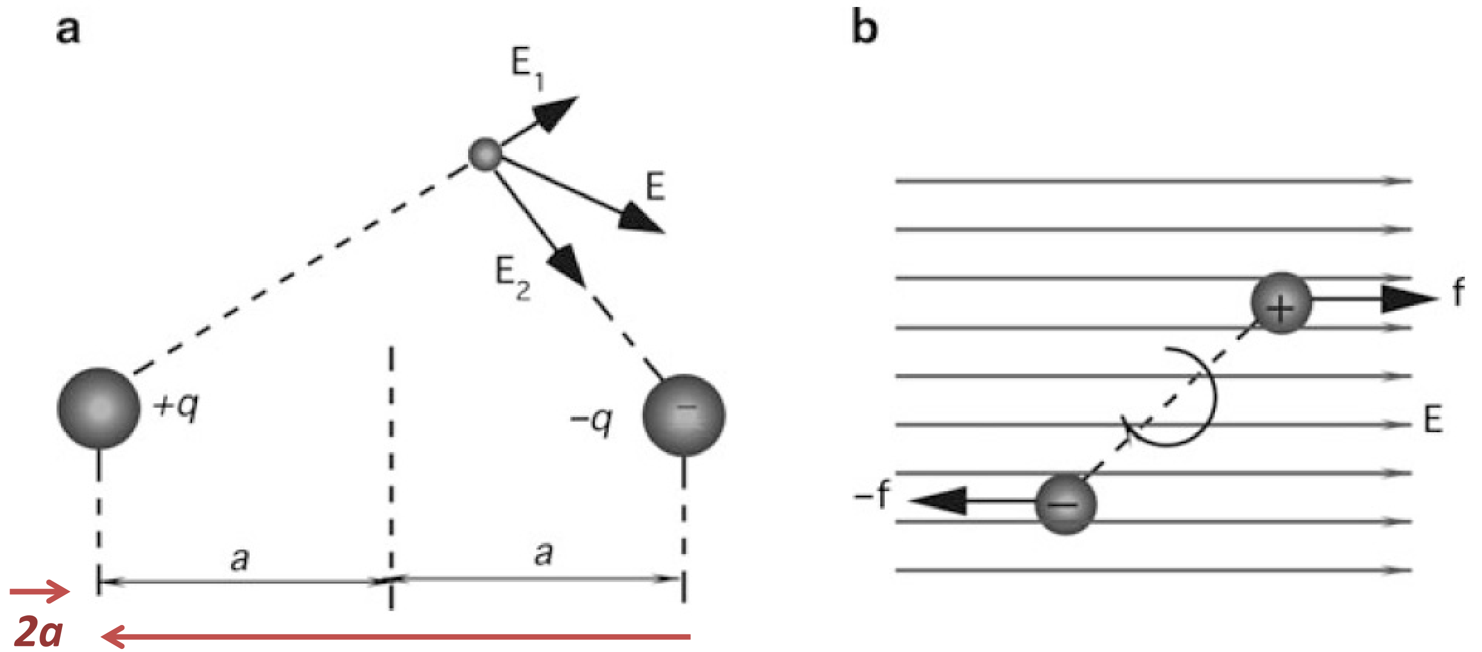


Fig. 3.3 Electric dipole (**a**); an electric dipole in an electric field is subjected to a rotating force (**b**)

Dipolmoment: $\boldsymbol{p} = 2q\boldsymbol{a}$

Felt fra dipol: $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{qa}{r^3}$

Dreimoment (torque): $\boldsymbol{\tau} = \boldsymbol{p} \times \boldsymbol{E}$

Poling av krystallinske polymerere med høy feltstyrke og varme
→ piezo- eller pyroelektriske materialer

Kapasitans

$$C = \frac{Q}{V} = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

Forskyvningssensor:

$$C = \frac{2\pi\varepsilon l}{\ln\frac{b}{a}}$$

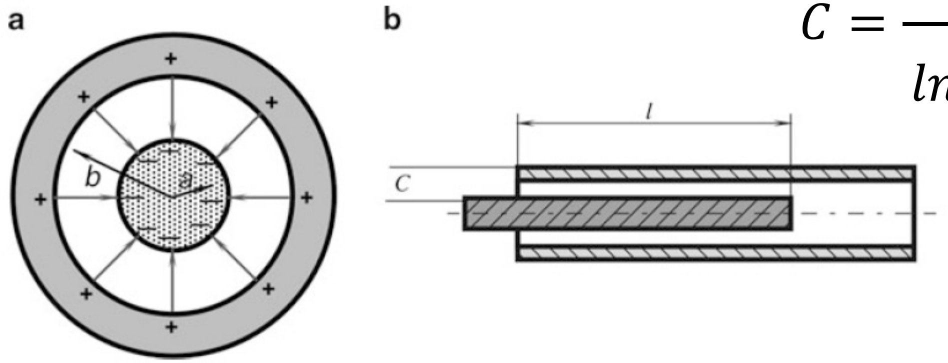
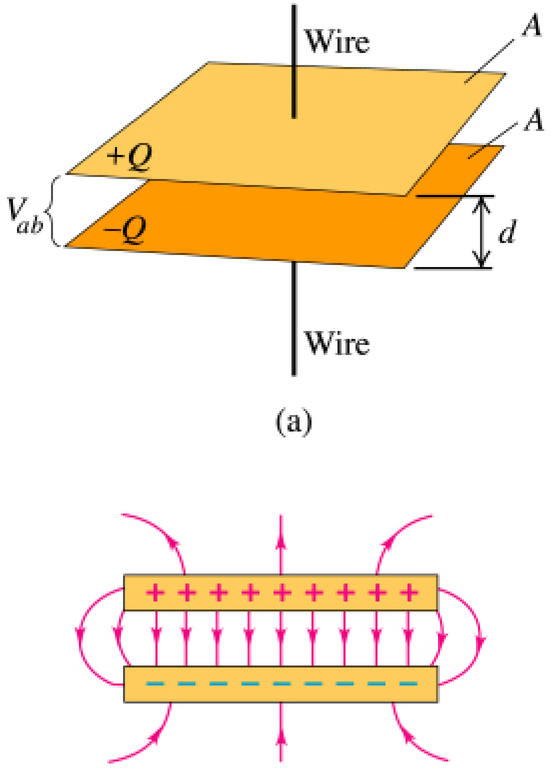
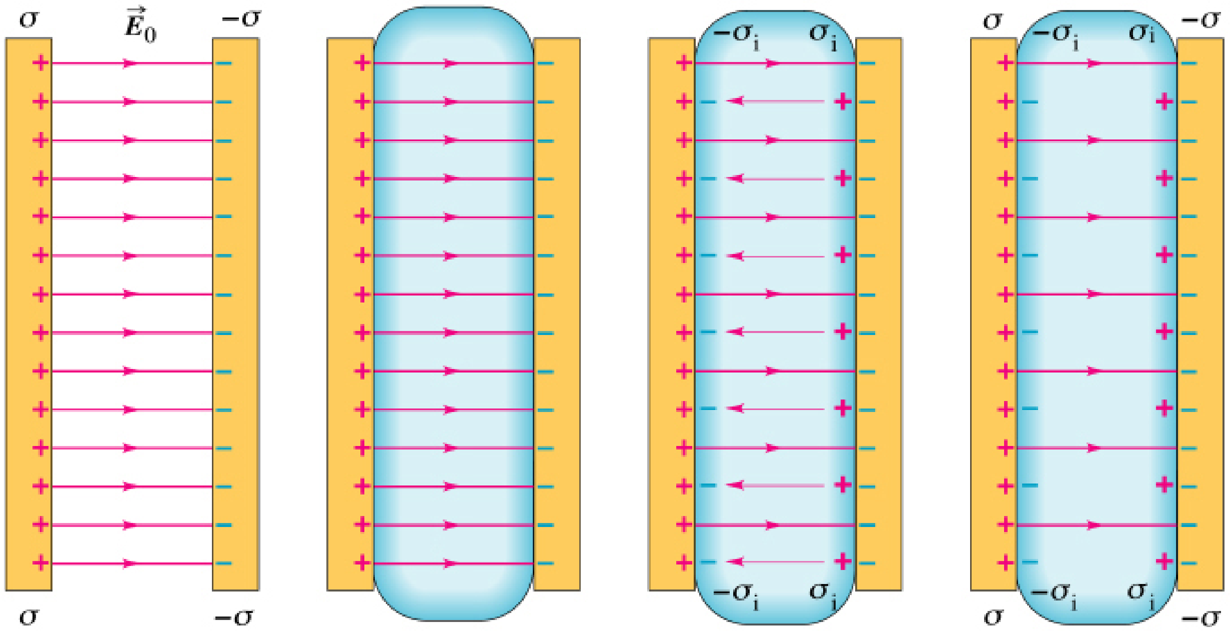


Fig. 3.5 Cylindrical capacitor (**A**); capacitive displacement sensor (**B**)



(a)

(b)



(a)

(b)

(c)

(d)

Permittivitet

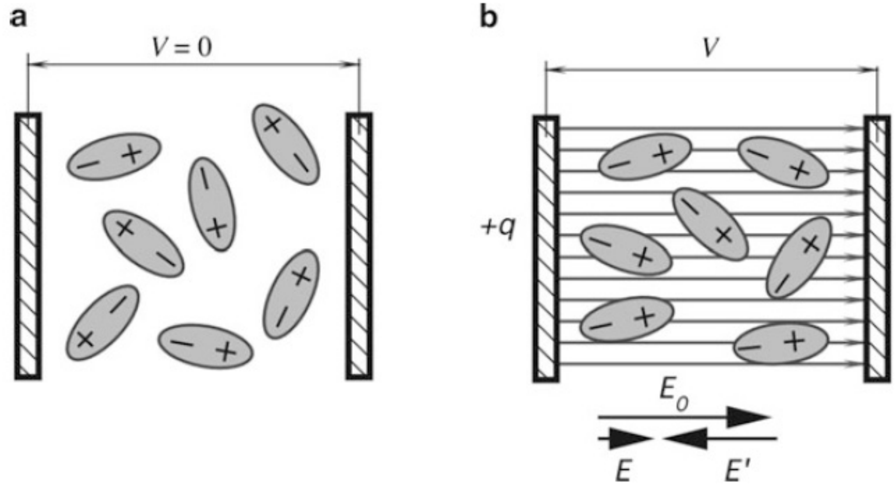


Fig. 3.6 Polarization of dielectric

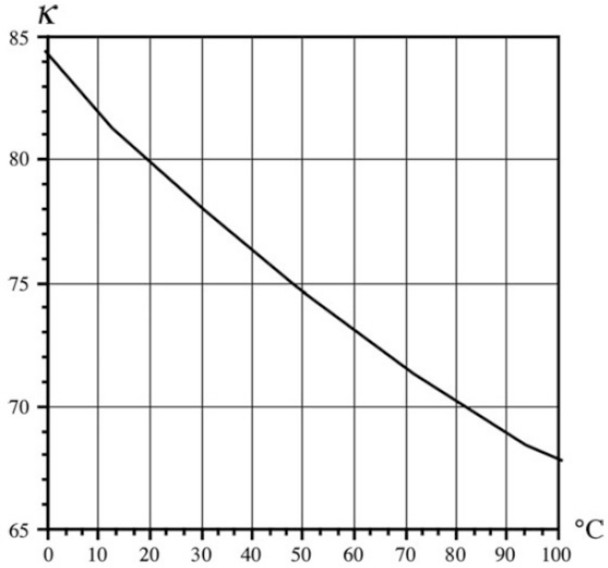


Fig. 3.7 Dielectric constant of water as a function of temperature

$$C = \frac{2\pi\varepsilon_0}{ln\frac{b}{a}}\left[H - h(1 - \varepsilon_r)\right]$$

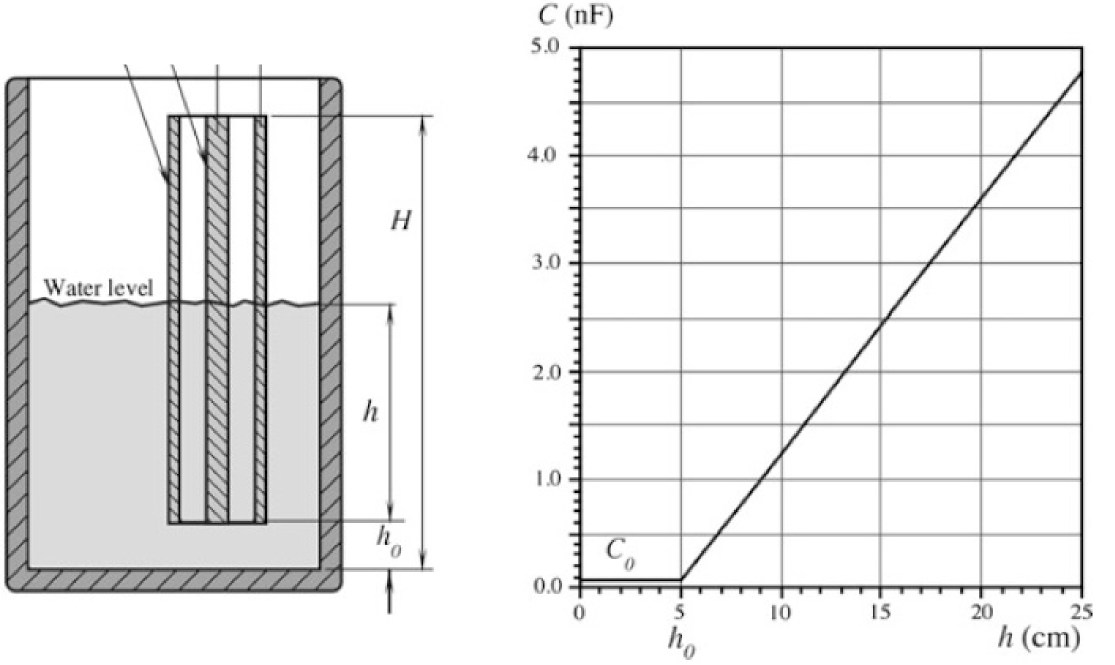


Fig. 3.8 Capacitive water level sensor (A); capacitance as function of the water level (B) (sensor's dimensions are as follows: a=10 mm, b = 12 mm, H = 200 mm, liquid—water)

Permittivitet forts.

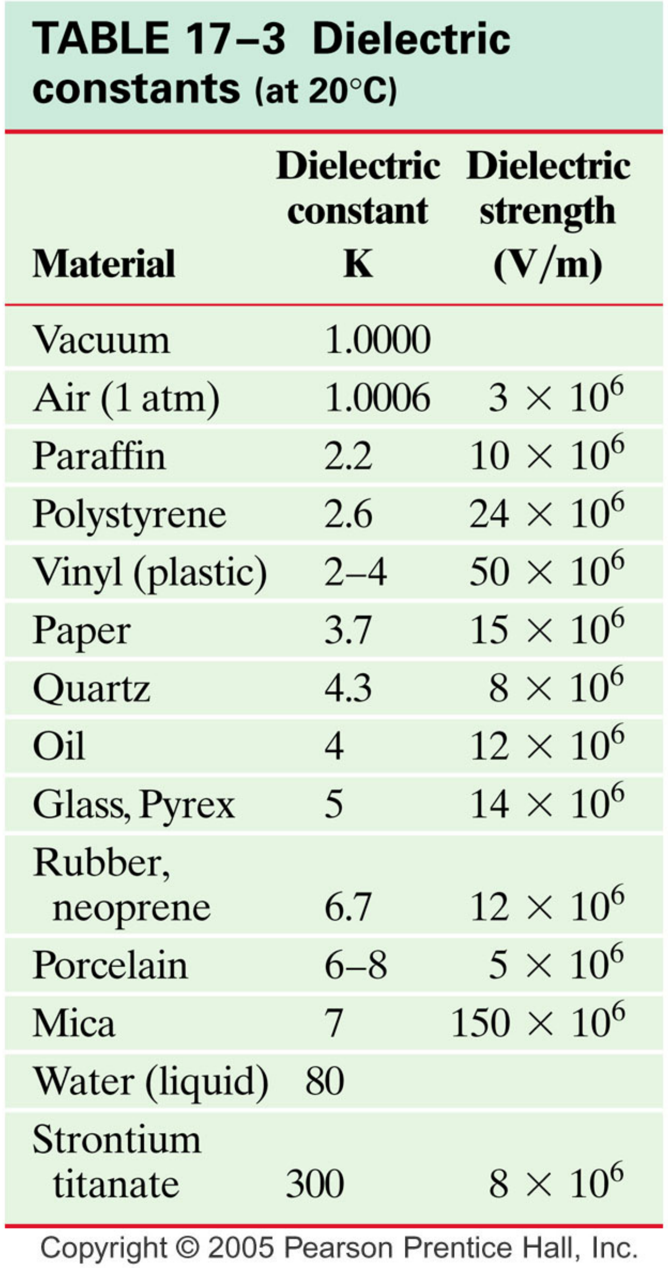
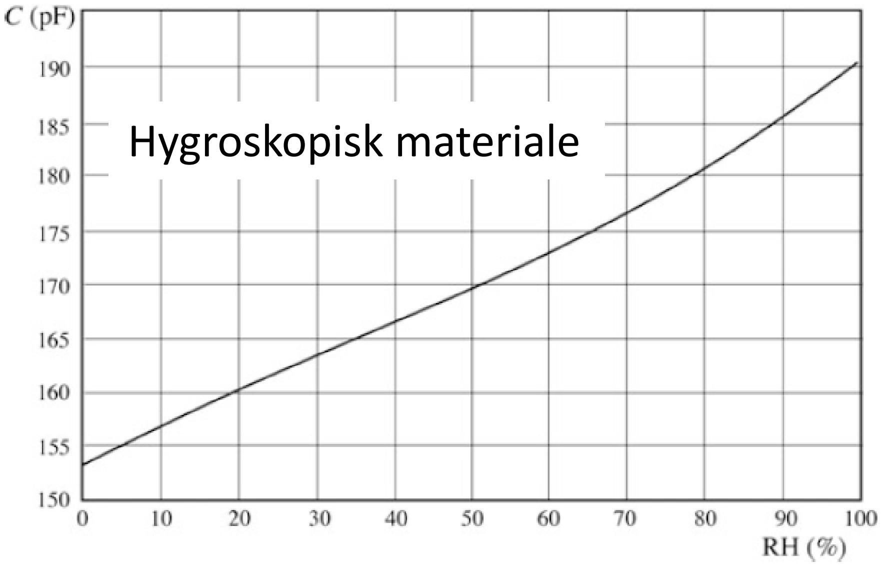


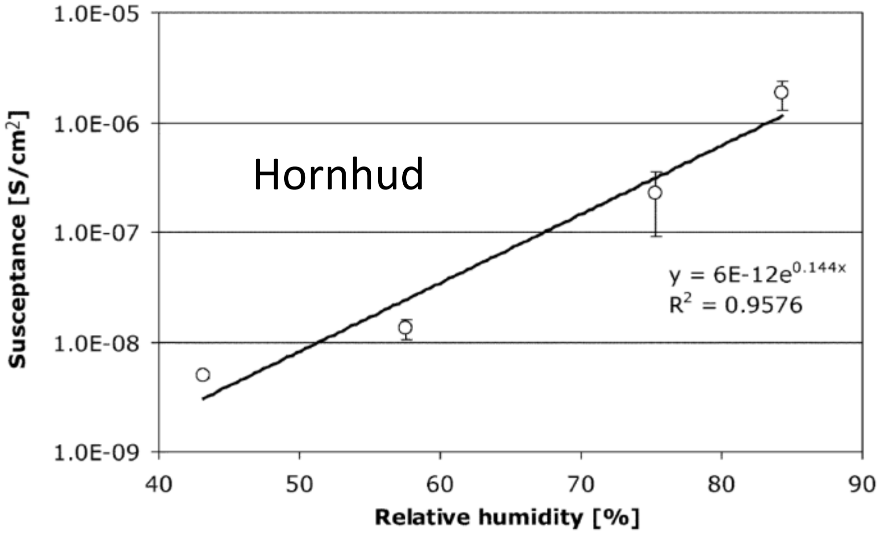
TABLE 17–3 Dielectric constants (at 20°C)

Material	Dielectric constant K	Dielectric strength (V/m)
Vacuum	1.0000	
Air (1 atm)	1.0006	3×10^6
Paraffin	2.2	10×10^6
Polystyrene	2.6	24×10^6
Vinyl (plastic)	2–4	50×10^6
Paper	3.7	15×10^6
Quartz	4.3	8×10^6
Oil	4	12×10^6
Glass, Pyrex	5	14×10^6
Rubber, neoprene	6.7	12×10^6
Porcelain	6–8	5×10^6
Mica	7	150×10^6
Water (liquid)	80	
Strontium titanate	300	8×10^6



Hygroskopisk materiale

Fig. 3.9 Transfer function of a capacitive relative humidity sensor



Hornhud

Magnetisme

- Hans Christian Ørsted (1820): Strøm påvirket kompassnål.
- Para-, dia- og ferromagnetisme. Sensorer for bevegelse, forskyvning og posisjon.

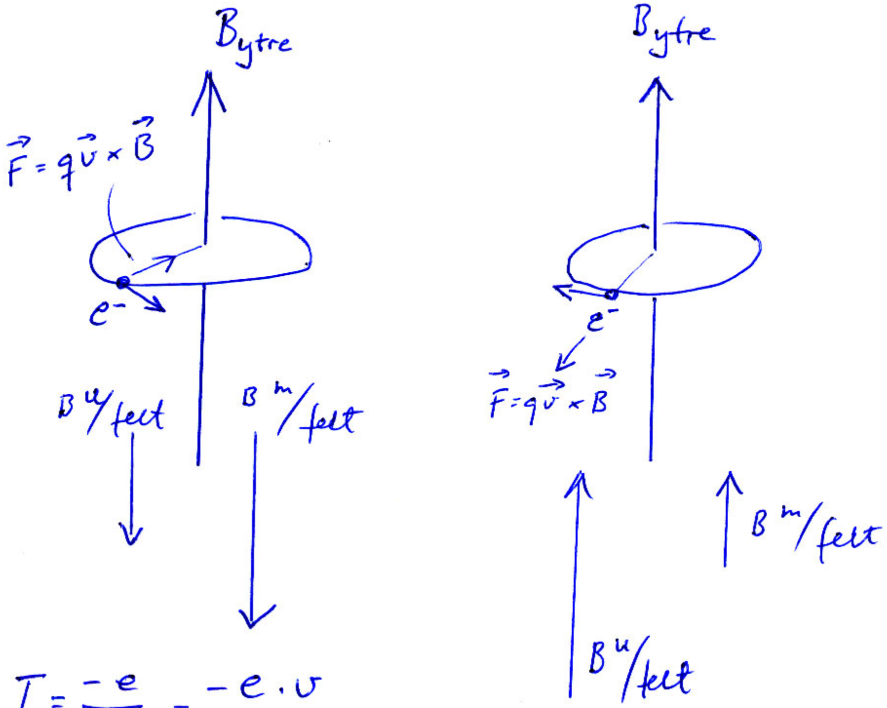
Paramagnetisme (eks. H)
Elektronets bane retter seg inn etter ytre felt og styrker dette.

Ferromagnetisme (eks. Fe)
Laveste energitilstand for uparede elektroner er parallelt spinn

Domains Before Magnetization

Domains After Magnetization

Diamagnetisme (eks. He)



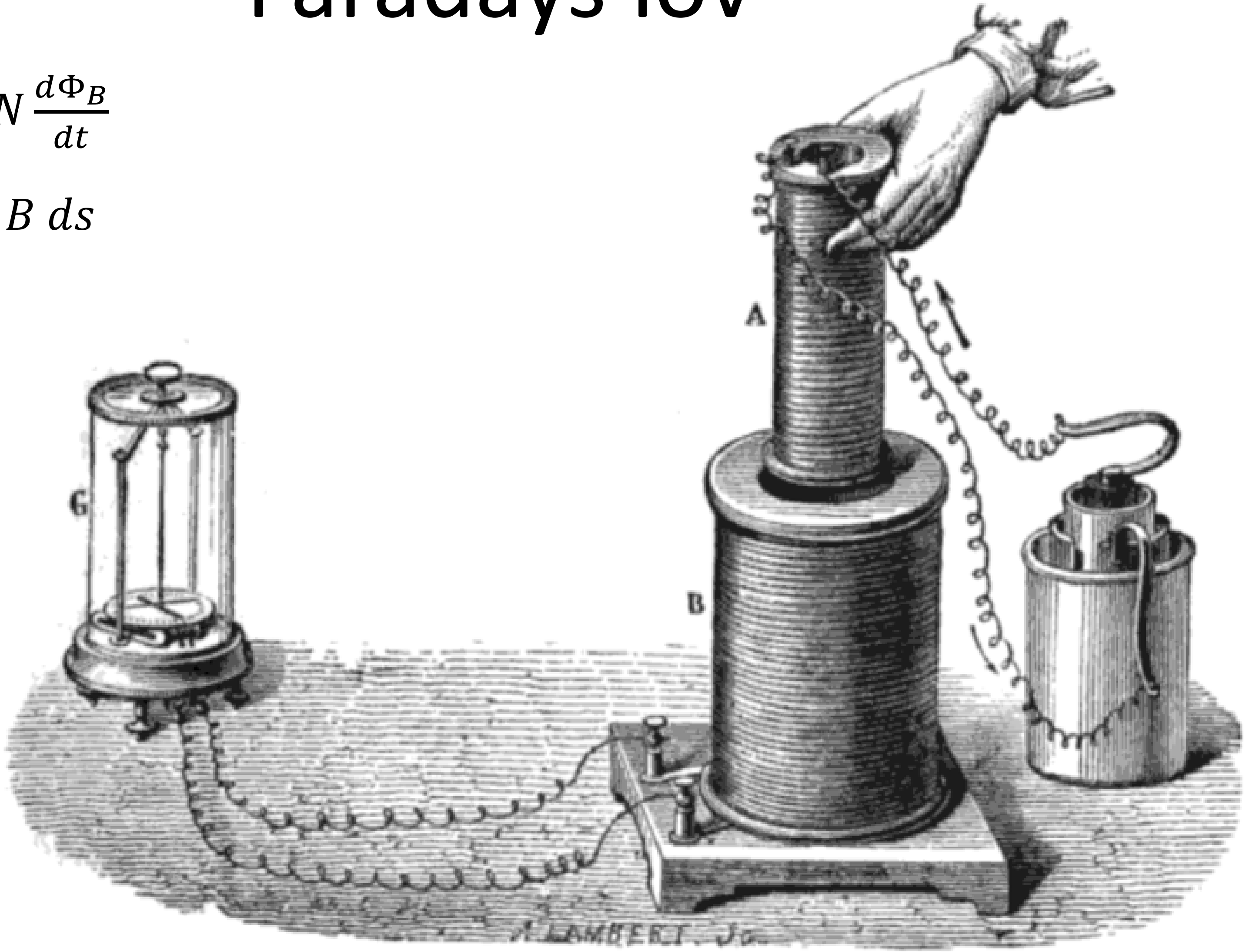
$$I = \frac{-e}{T} = \frac{-e \cdot v}{2\pi r}$$

mindre r ⇒ høyere I

Faradays lov

$$\text{ems} = -N\frac{d\Phi_B}{dt}$$

$$\Phi_B = \oint B\, ds$$



Spole

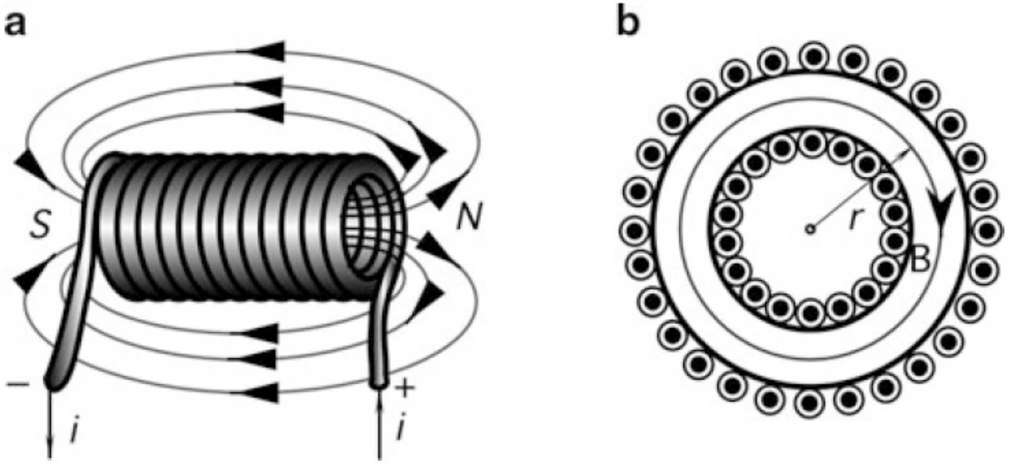


Fig. 3.14 Solenoid (**a**) and toroid (**b**)

$B = \mu_0 \cdot n \cdot I$ (n er viklinger per lengde)

$L = \mu_0 \cdot n^2 \cdot A \cdot l$ (μ_0 er magnetisk permeabilitet $4 \cdot \pi \cdot 10^{-7}$ Tm/A)

Resistans – temperatursensitivitet

- Resistivitet eller konduktivitet som oftest temperaturavhengig
- Lineær innenfor snevert område:

$$\rho = \rho_0 \left(1 + \alpha \frac{t - t_0}{t_0}\right)$$

- α er temperaturkoeffisienten
- God motstand: $\alpha \leq 10^{-5}$
- Mer nøyaktig:
  $\rho = 4.45 + 0.0269\, t + 1.914\times10^{-6}\, t^2$
- Metaller: PTC
- Halvledere og en del oksyder: NTC
- Ohme en glødelampe …
- Termistor: Ønsker høy α

Tungsten = Wolfram

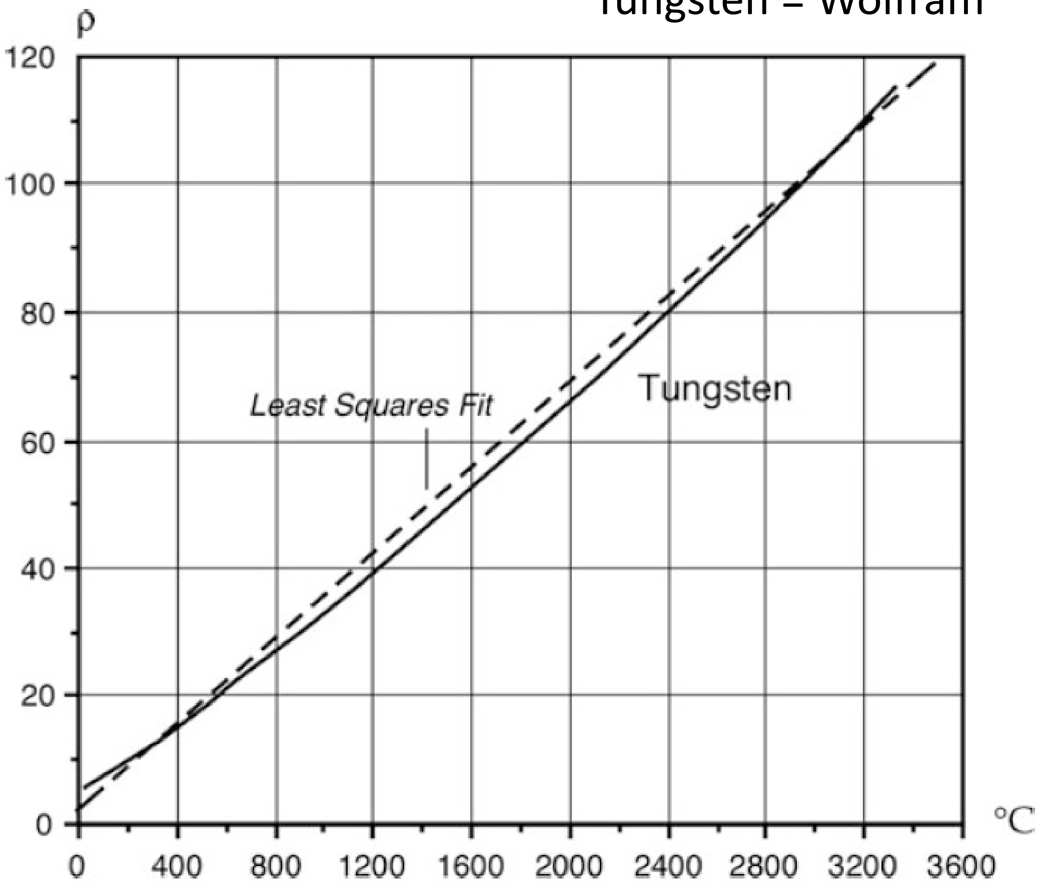
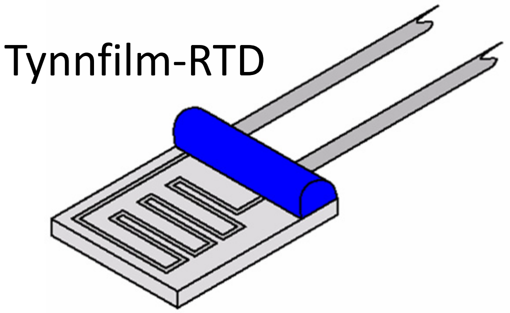


Fig. 3.17 Specific resistivity of tungsten as function of temperature

Temperaturmåling forts.

Tynnfilm-RTD



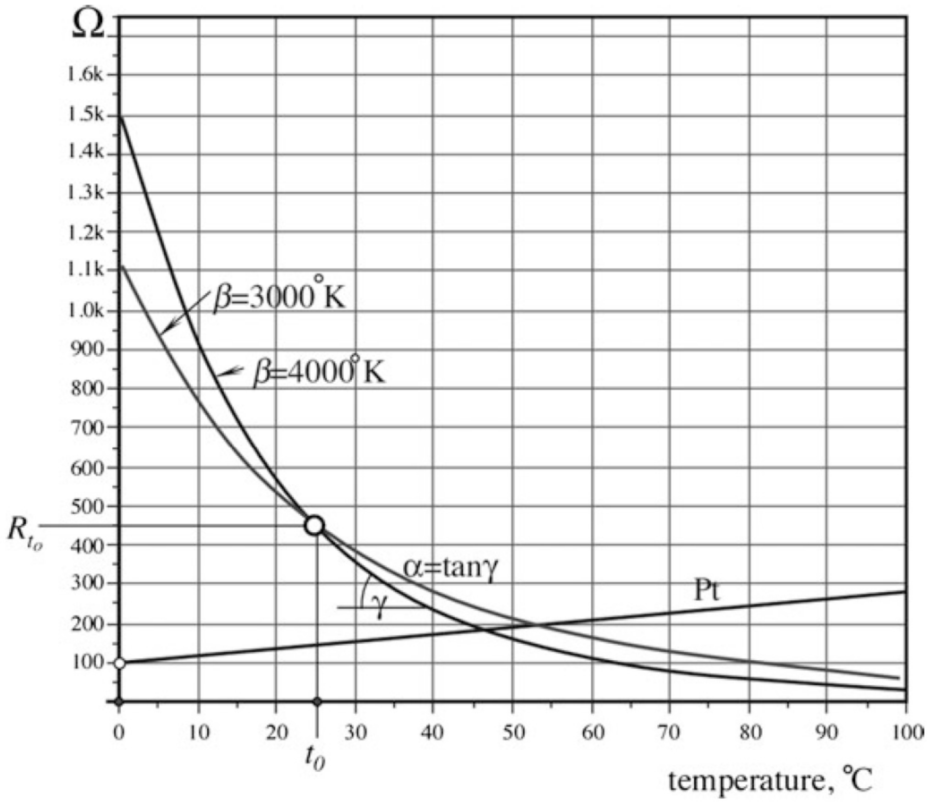


Fig. 3.18 Resistance-temperature characteristics for two thermistors and Pt RTD (Ro=1k); thermistors are calibrated at t_o=25°C and RTD at 0°C

- Resistance Temperature Detectors (RTD)
- Av rent materiale; platina, nikkel, kobber, osv.
- RTD tar langsomt over for thermocouple (*senere*)
- Termistorer lages av halvledermaterialer. De har snevrere måleområde, er mindre lineære og stabile, men er sensitive, robuste og billige.
- $R_t = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)}$
- β er karakteristisk temperatur

Resistans – belastningsfølsomhet (strain)

- R endres pga. endring i ρ eller i geometri
- Kalles piezoresistiv effekt
- Brukes i kraft- og trykksensorer
- Young's modul er et mål på stivheten hos et elastisk materiale

Stress (trykk): $\sigma = \frac{F}{a} = E\frac{dl}{l}$

Young's modul

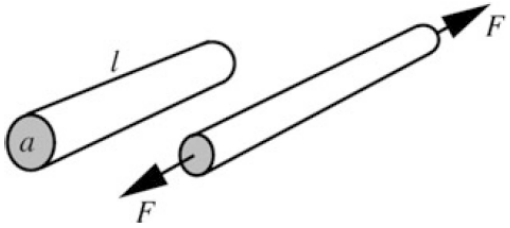
Strain *e*

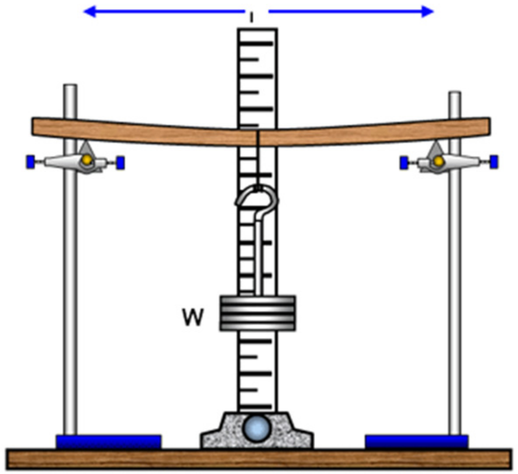
$$R = \rho\frac{l}{a} = \rho\frac{l^2}{v}$$

Sensitivity: $\frac{dR}{dl} = 2\rho\frac{l}{v}$

$$\frac{dR}{R} = S_e e$$

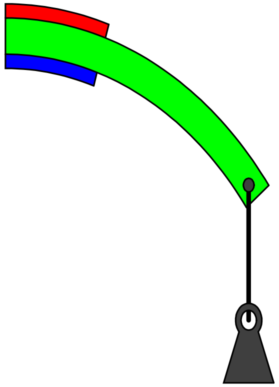
Gauge factor / sensitivity (metaller: 2-6, halvledere: 40-200)



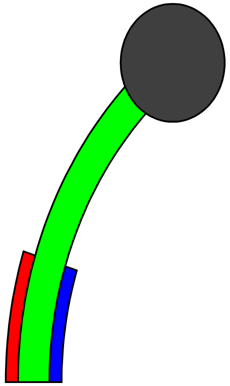


(resourcefulphysics.org)

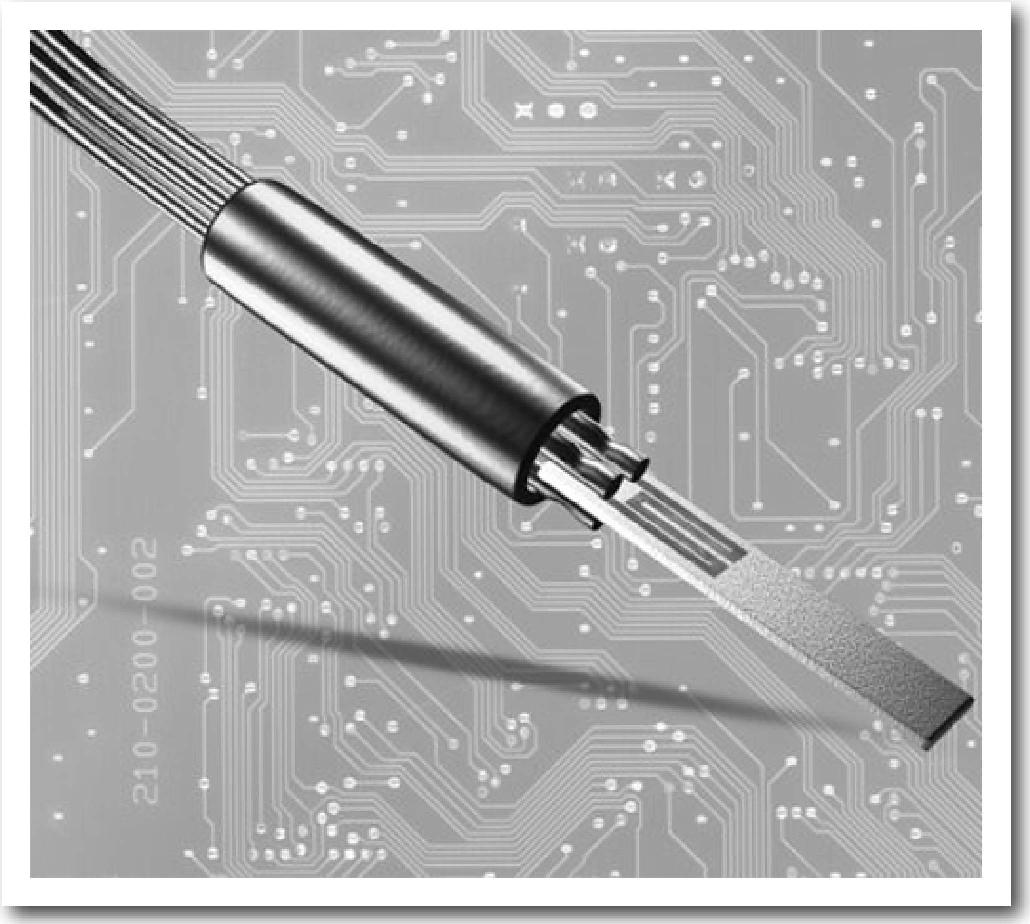
Bruksområder

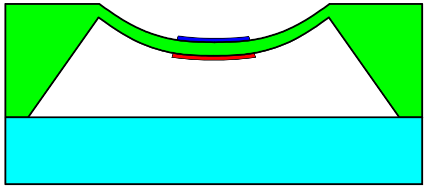


Veieceller



Akselerometer

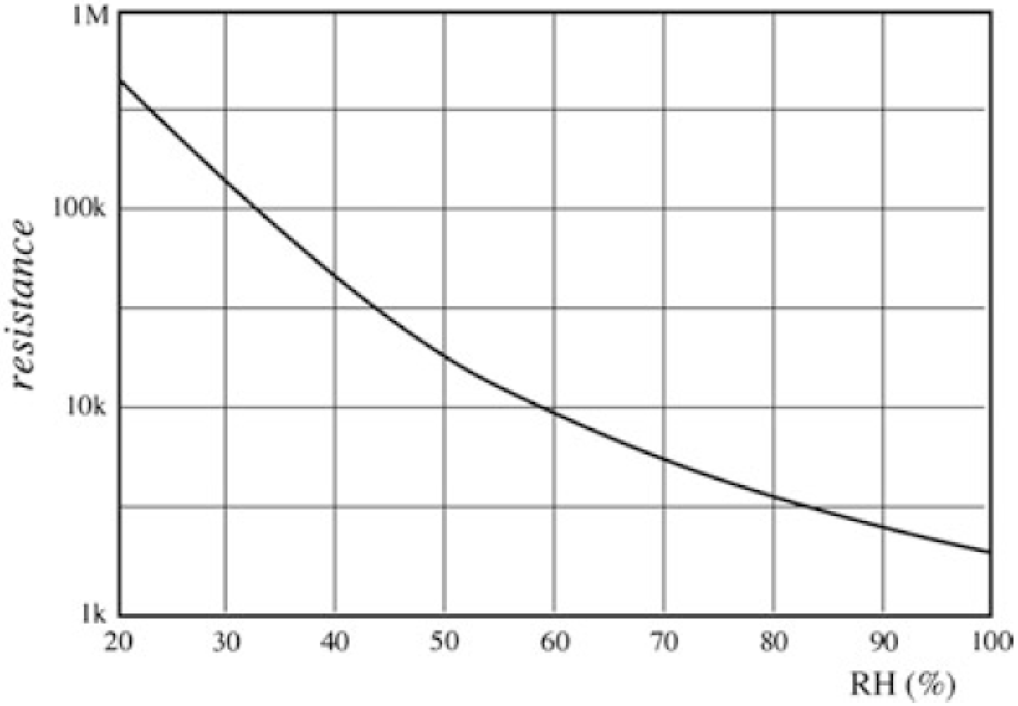




Trykksensorer

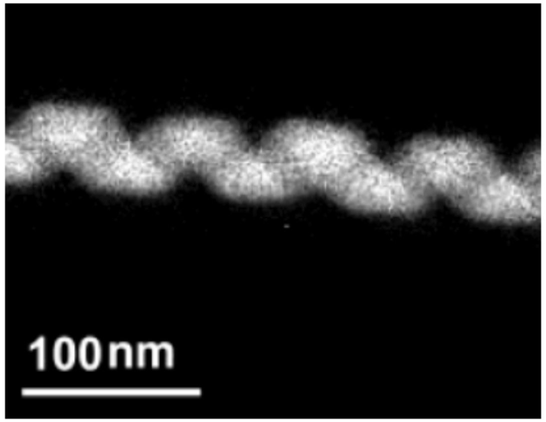
Resistans – fuktighetsfølsomhet

- Motstand av hygroskopisk materiale: hygristor
- Keramisk substrat med to interdigitaliserte elektroder (silketrykk)
- Responstid 10 – 30 sek, R = 1 – 1000 kΩ
- Må eksiteres med AC for å unngå polarisasjon

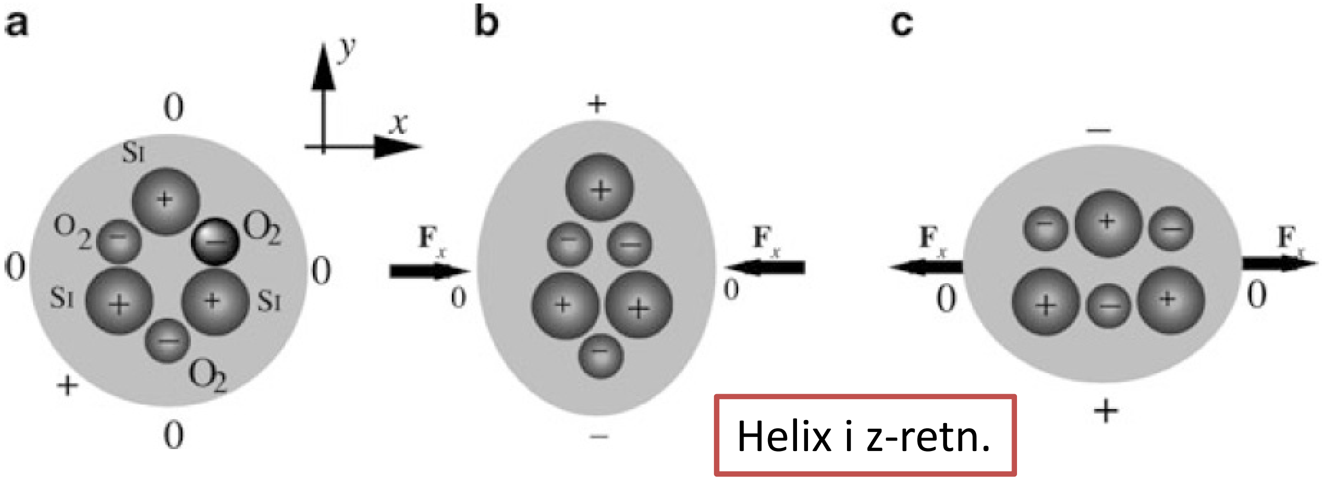


Piezoelektrisk effekt

- Krystaller, polede keramer, noen polymere
- Kvarts: SiO_2 – danner helixer
- Enkel modell av A. Meissner (1927) vist i 3.21
- Må ha elektroder på hver side
- Effekten er resiprok
- Se boka for definisjon av flere koeffisienter



Synthesis, Characterization, and Manipulation of Helical SiO_2 Nanosprings
H. F. Zhang, C. M. Wang, E. C. Buck, and L. S. Wang
Nano Lett. **3**, 577-580 (2003). [PDF]



Helix i z-retn.

Fig. 3.21 Piezoelectric effect in a quartz crystal

Keramiske piezoelektriske materialer

- Metalloksyder
- Krystallinske material har tilfeldig orienterte dipoler
- Poling ved oppvarming i felt eller korona-utladning
- Det indre feltet forsvinner over tid (fig. c), men ved trykk eller f.eks. luftstrøm over elektrodene gjenopprettes feltet
- Dette er altså en AC-enhet
- *Se Fraden for piezoelektrisk polymere*

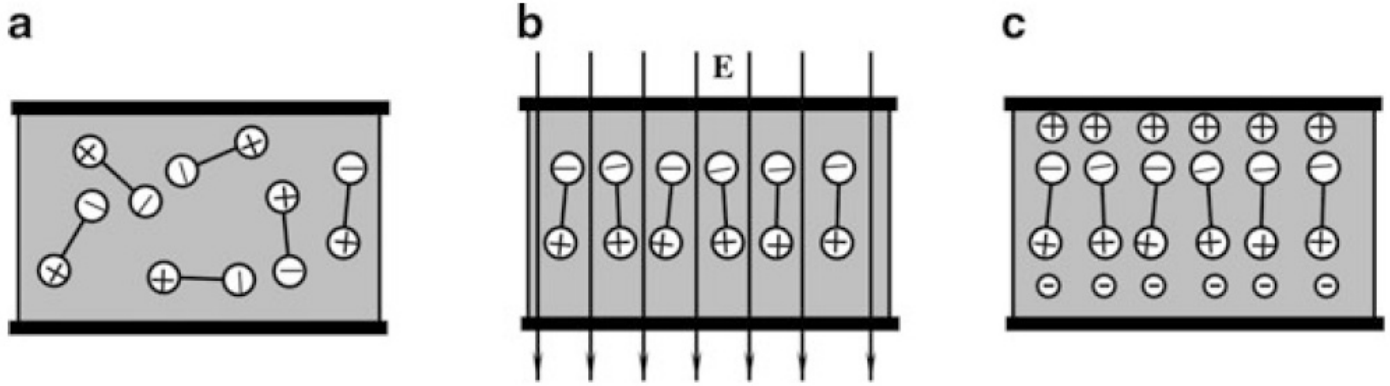
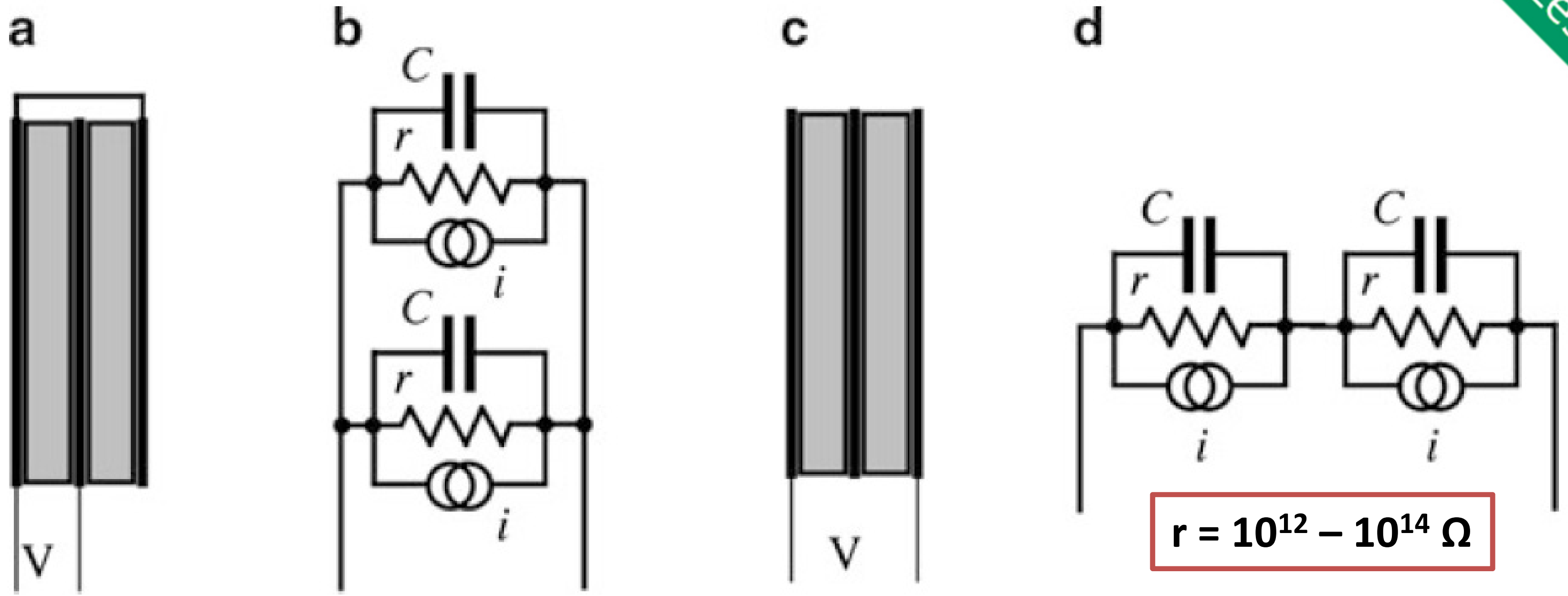


Fig. 3.23 Thermal poling of a piezo- and pyroelectric material

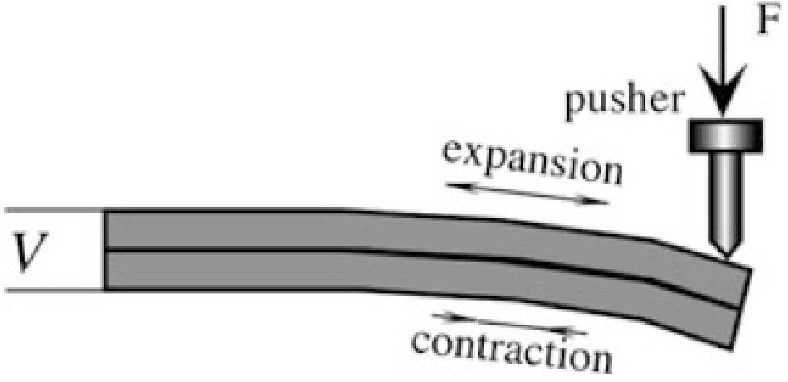
Les selv ...



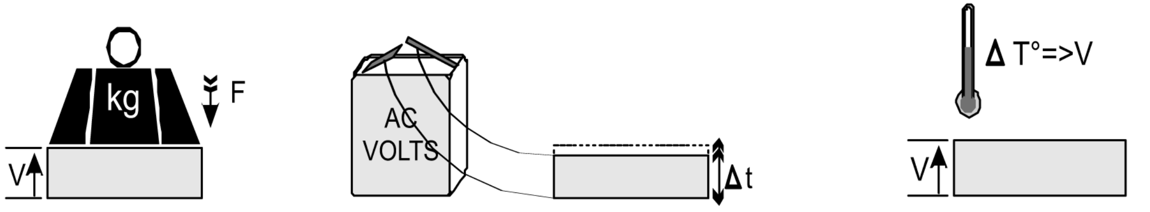
r = $10^{12} – 10^{14}$ Ω

Fig. 3.24 Parallel (**a**) and serial (**c**) laminated piezoelectric sensors and their corresponding equivalent circuits (**b**), (**d**)

Fig. 3.25 Laminated two-layer piezoelectric sensor



Pyroelektrisk effekt



Direct piezo effect:

MECHANICAL STRESS
=> ELECTRICAL CHARGES

Reverse piezo effect:

ELECTRICAL SIGNAL
=> MECHANICAL STRAIN

Pyroelectric effect:

TEMPERATURE CHANGE
=> ELECTRICAL CHARGES

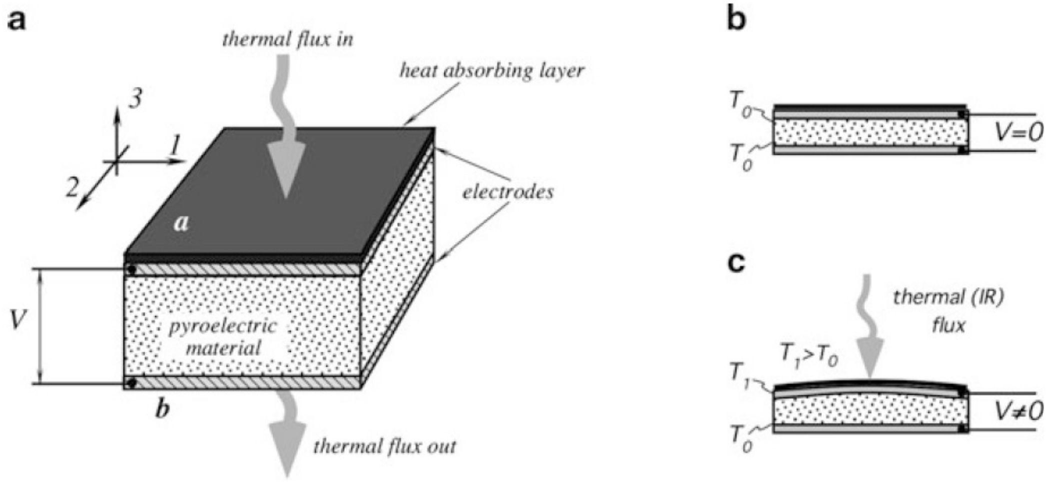


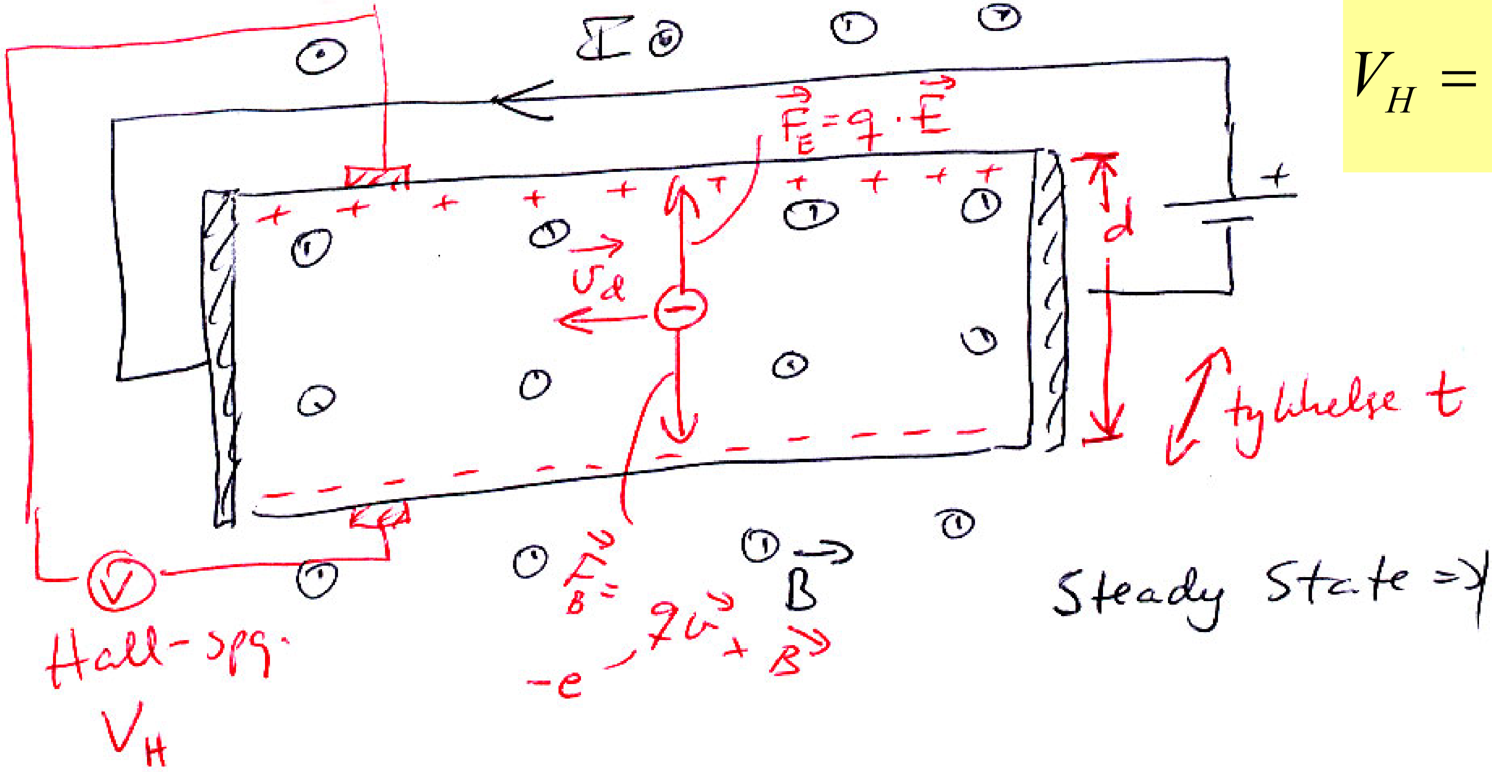
Fig. 3.26 Pyroelectric sensor has two electrodes at the opposite sides of the crystal (**a**). Thermal radiation is applied along axis 3 from the top and absorbed by the heat absorbing layer. Heat conductively travels through the pyroelectric material and is partially emanated downward from side *a*. Pyroelectric sensor in a neutral state (**b**); heat expands the upper layer, resulting in a piezoelectric charge (**c**)

- Konverterer varme-endring til elektrisk signal
- De er også piezoelektriske
- De poles på samme måte som piezo-materialer
- Primæreffekt:
  - Varmeutvidelse gir endring i dipolstørrelse
  - Endring i dipolenes orientering
- Sekundæreffekt
  - Strekk i materialet pga termisk utvidning
- Se Fraden for karakteristiske parametere

Hall-effekt

- E.H. Hall (Johns Hopkins University), 1879
- Konstant *I* → V_H prop med ***B*** (krever B > 1 mT)
- Kan finne $n \cdot q$ – altså bestemme n (ladninger per volumenhet)

$$V_H = \frac{I \cdot B}{n \cdot q \cdot t}$$



Steady State $\Rightarrow |F_B| = |F_E|$

Termoelektriske effekter: Seebeck-effekt

- T.J. Seebeck (1770-1831), Estland
- Den absolutte Seebeck koeffisienten:

$$\alpha_a = \frac{dV_a}{dT}$$

- Skyldes Thompson-effekt: termiske gradienter i en leder gir strøm

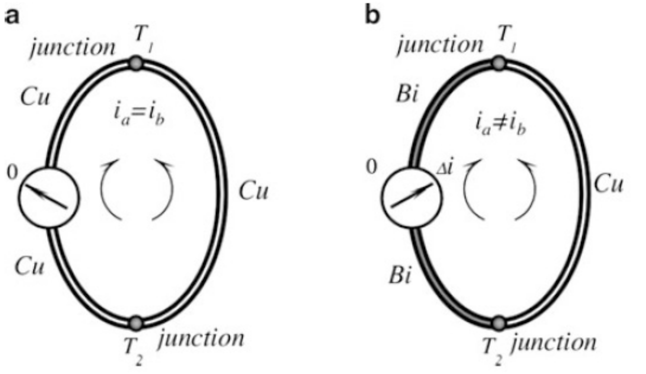


Fig. 3.35 Thermoelectric loop
Joints of identical metals produce zero net current at any temperature difference (**a**); joints of dissimilar metals produce net current Δi (**b**)

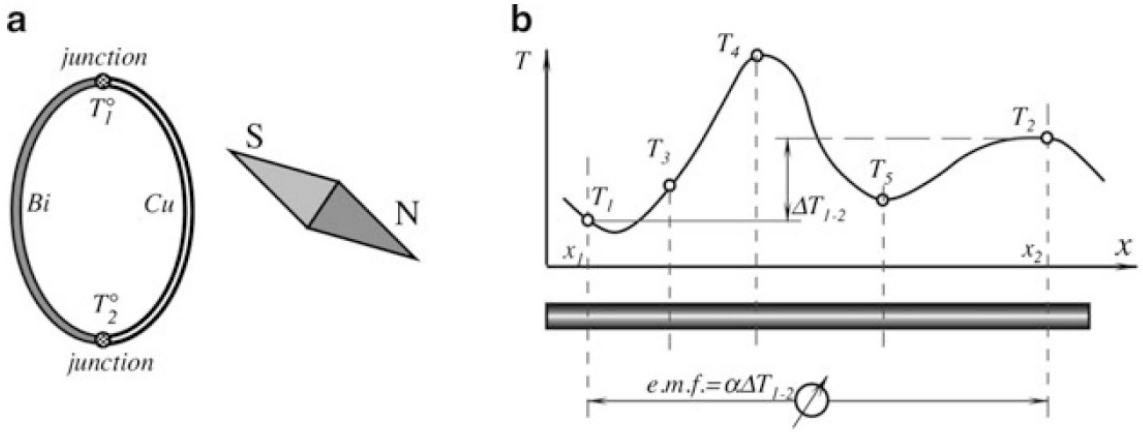
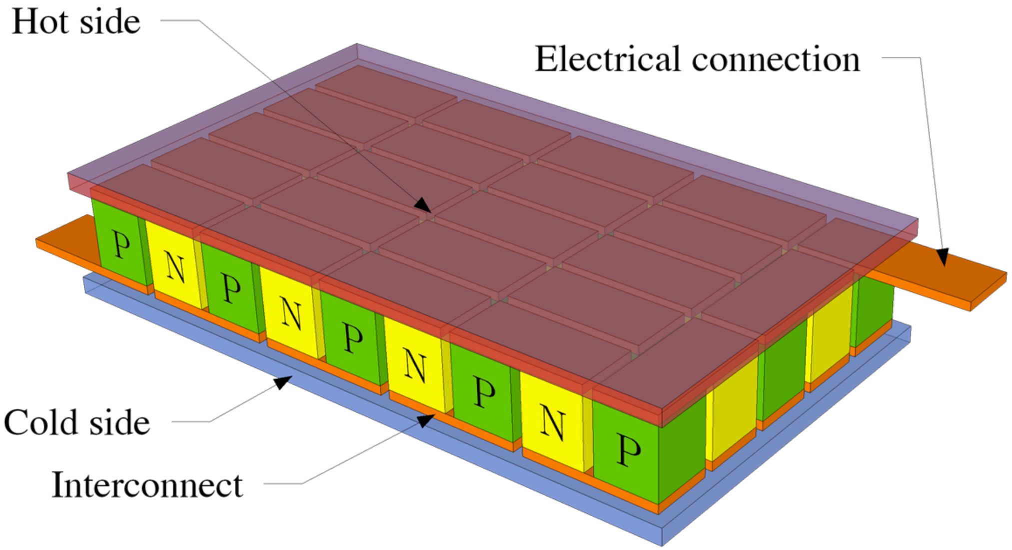


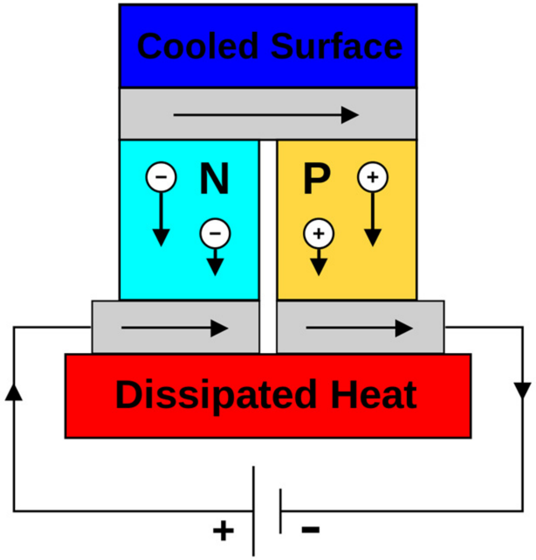
Fig. 3.34 Seebeck experiment (**a**), varying temperature along a conductor is a source of a thermoelectric e.m.f. (**b**)

- Vanskelig å måle fordi man innfører flere metaller
- En termisk indusert *ems* finnes i alle metaller som ikke er i termisk likevekt
- Må ha to metaller for å få netto effekt (thermocouple)

Termoelektriske effekter: Peltier-effekt

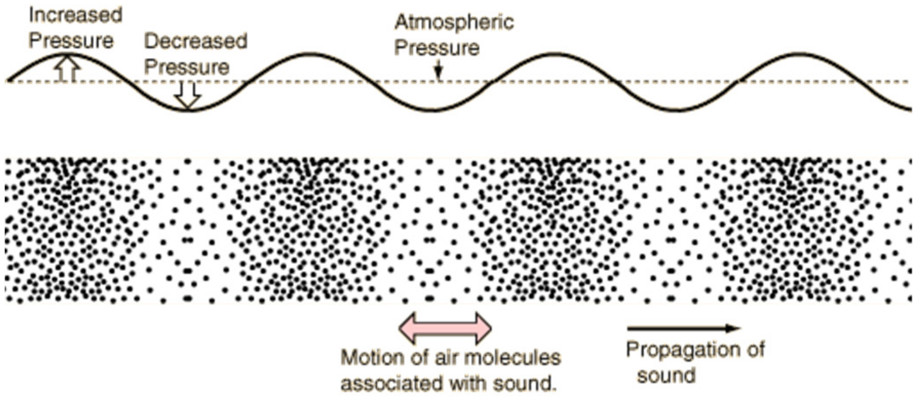
- J.C.A Peltier (1785-1845), fransk fysiker
- Reversert Seebeck-effekt brukt til å produsere temperatur-gradient
- For oppvarming eller nedkjøling





Lydbølger

Infralyd – 20 Hz – 20 kHz – ultralyd



Elastisitetsmodul: $B = \frac{\Delta p}{\Delta V / V_0} = \rho_0 v^2$

Lydhastighet: $v = \sqrt{\frac{B}{\rho_0}}$

Akustisk impedans (uten tap): $Z = \rho_0 v$

Lydnivaa: $\beta = 10\log_{10}\left(\frac{I}{I_0}\right)$

Sound source	dB
Rocket engine at 50 m	200
Supersonic boom	160
Hydraulic press at 1 m	130
Threshold of pain	120
10W Hi-Fi speaker at 3 m	110
Unmuffled motorcycle	110
Rock-n-roll band	100
Subway train at 5 m	100
Pneumatic drill at 3 m	90
Niagara Falls	85
Heavy traffic	80
Automobiles at 5 m	75
Dishwashers	70
Conversation at 1 m	60
Accounting office	50
City street (no traffic)	30
Whisper at 1 m	20
Rustle of leaves	10
Threshold of hearing	0

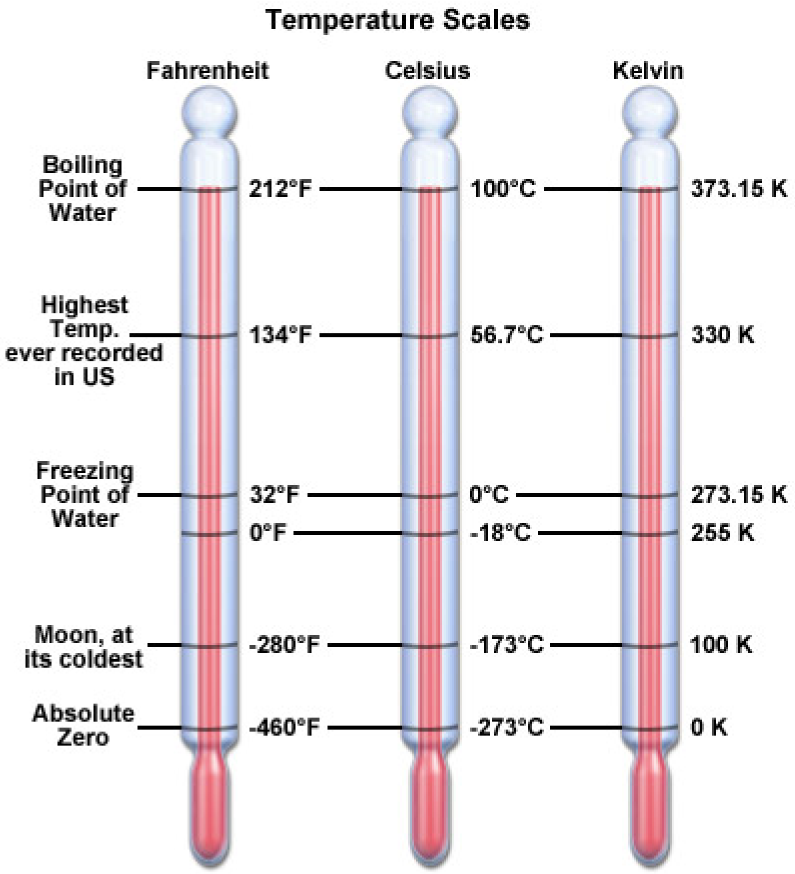
Table A.15 Speed of sound waves

Medium	Speed (m/s)
Air (dry at 20°C)	331
Steam (134°C)	494
Hydrogen (20°C)	1,330
Water (fresh)	1,486
Water (sea)	1,519
Lead	1,190
Copper	3,810
Aluminum	6,320
Pyrex® glass	5,170
Steel	5,200
Beryllium	12,900

Gases at 1 atm pressure, solids in long thin rods

Temperaturskalaer

- Daniel Gabriel Fahrenheit, Hollender, 1706
  - 0: Det laveste han kunne produsere av vann, is og salt
  - 96: Normal kroppstemperatur
  - 96 var praktisk for da kunne han lett lage delstreker ved å dele på to (48, 24, 12, ...)
- Andreas Celsius, Svensk, 1742
  - 0: Smeltepunkt for is
  - 100: Kokepunkt for vann
- Lord William Thomson Kelvin, Britisk, 1824-1907
  - 0: Absolutt nullpunkt



Termisk utvidelse

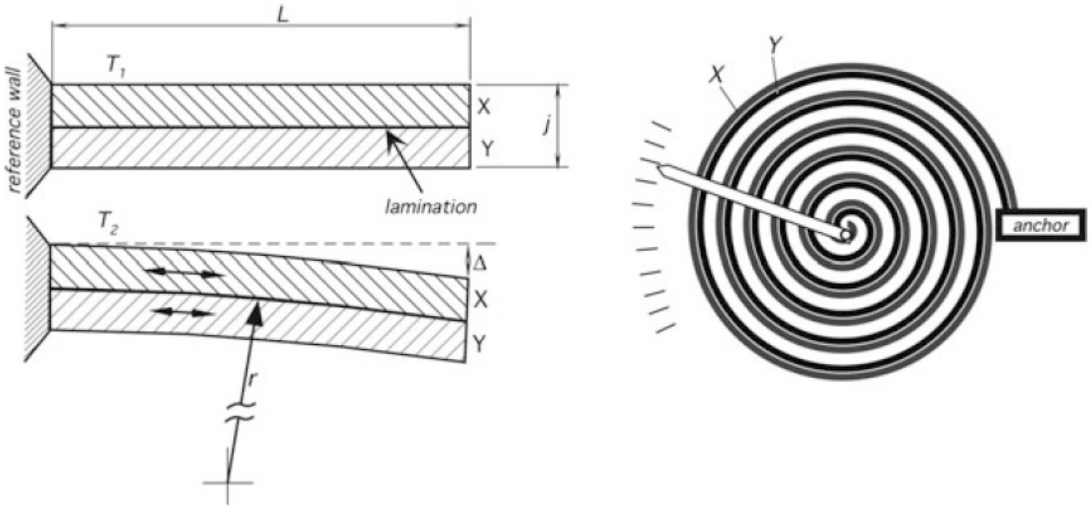


Fig. 3.38 Warping of a laminated plate where two materials have different coefficients of thermal expansion (**a**); bi-metal coil used as a temperature transducer (**b**)

$$l_2 = l_1[1 + \alpha(T_2 - T_1)]$$

$$\Delta A = 2\alpha A \Delta T$$
$$\Delta V = 3\alpha V \Delta T$$

Bøyeradius: $r \approx \dfrac{2j}{3(\alpha_X - \alpha_Y)(T_2 - T_1)}$

Table A.16 Coefficient (α) of linear thermal expansion of some materials (per °C$\times 10^{-6}$)

Material	α	Material	α
Alnico I (Permanent magnet)	12.6	Nylon	90
Alumina (polycrystalline)	8.0	Phosphor-bronze	9.3
Aluminum	25.0	Platinum	9.0
Brass	20.0	Plexiglas (Lucite)	72
Cadmium	30.0	Polycarbonate (ABS)	70
Chromium	6.0	Polyethylene (high density)	216
Comol (Permanent magnet)	9.3	Silicon	2.6
Copper	16.6	Silver	19.0
Fused quartz	0.27	Solder 50–50	23.6
Glass (Pyrex®)	3.2	Steel (SAE 1020)	12.0
Glass (regular)	9.0	Steel (stainless: type 304)	17.2
Gold	14.2	Teflon	99
Indium	18.0	Tin	13.0
Invar	0.7	Titanium	6.5
Iron	12.0	Tungsten	4.5
Lead	29.0	Zinc	35.0
Nickel	11.8		

Varme-kapasitet

= hvor mye varme Q (termisk/kinetisk energi) kan et objekt lagre?

$$C = cm$$

$$c = \frac{Q}{m\Delta T}$$

C = varmekapasitet
c = spesifikk varme

En temperatursensor med liten spesifikk varme vil forstyrre måleobjektet mindre

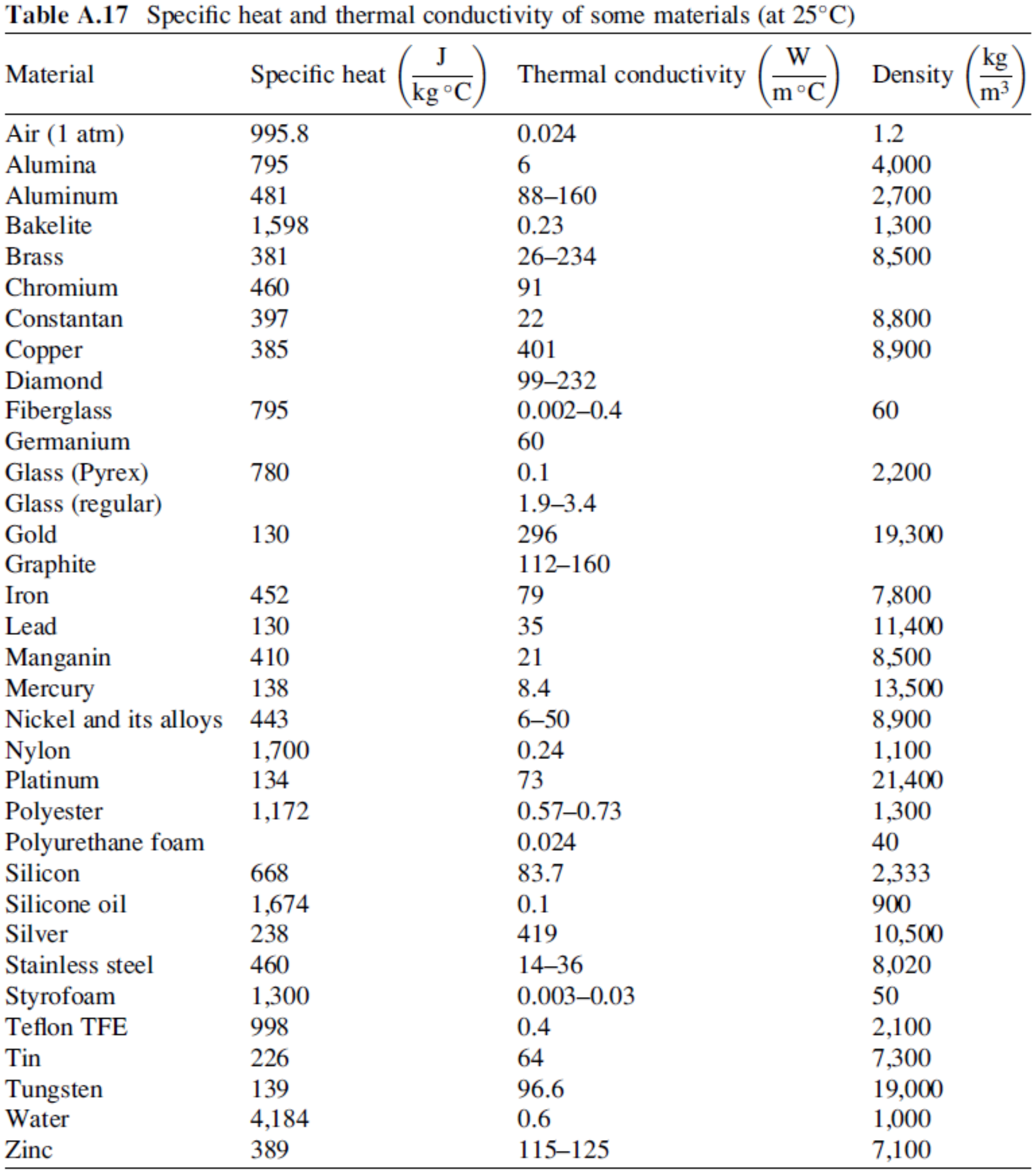
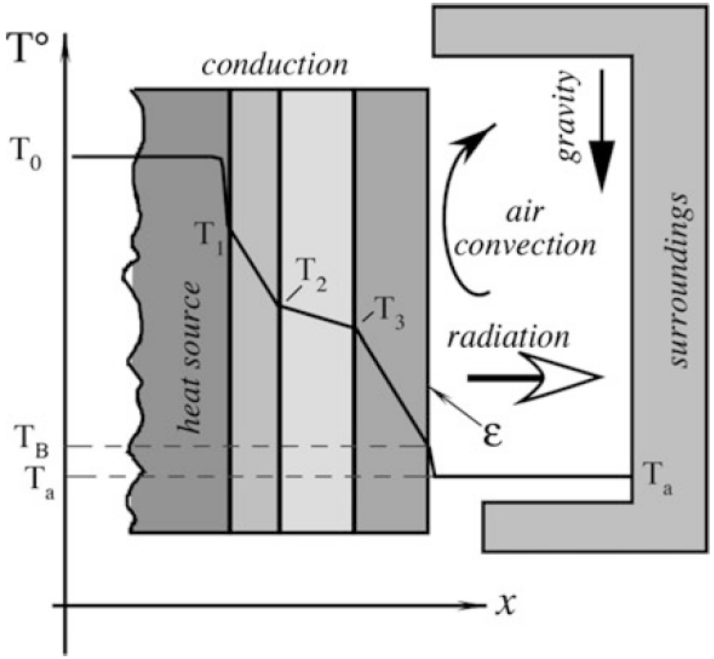


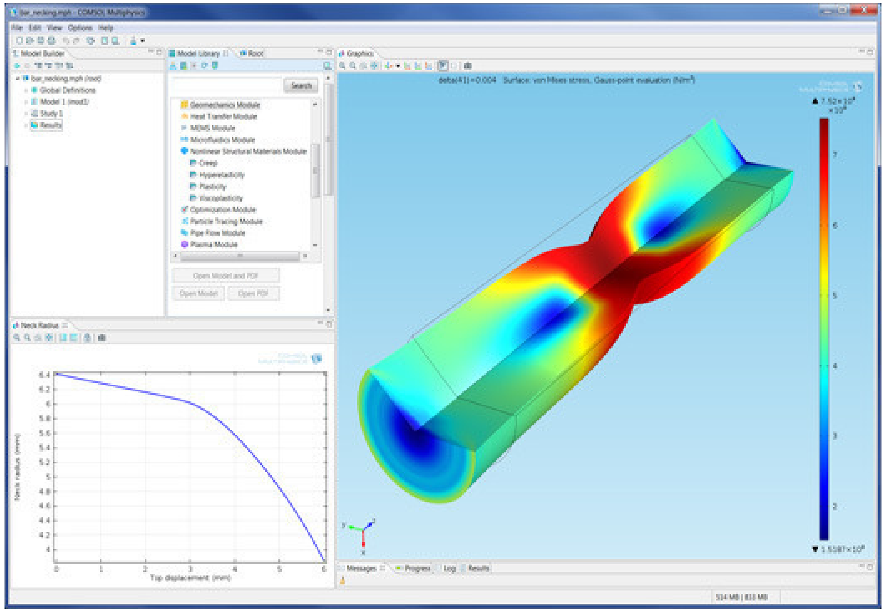
Table A.17 Specific heat and thermal conductivity of some materials (at 25°C)

Material	Specific heat $\left(\frac{\text{J}}{\text{kg}\,^\circ\text{C}}\right)$	Thermal conductivity $\left(\frac{\text{W}}{\text{m}\,^\circ\text{C}}\right)$	Density $\left(\frac{\text{kg}}{\text{m}^3}\right)$
Air (1 atm)	995.8	0.024	1.2
Alumina	795	6	4,000
Aluminum	481	88–160	2,700
Bakelite	1,598	0.23	1,300
Brass	381	26–234	8,500
Chromium	460	91	
Constantan	397	22	8,800
Copper	385	401	8,900
Diamond		99–232	
Fiberglass	795	0.002–0.4	60
Germanium		60	
Glass (Pyrex)	780	0.1	2,200
Glass (regular)		1.9–3.4	
Gold	130	296	19,300
Graphite		112–160	
Iron	452	79	7,800
Lead	130	35	11,400
Manganin	410	21	8,500
Mercury	138	8.4	13,500
Nickel and its alloys	443	6–50	8,900
Nylon	1,700	0.24	1,100
Platinum	134	73	21,400
Polyester	1,172	0.57–0.73	1,300
Polyurethane foam		0.024	40
Silicon	668	83.7	2,333
Silicone oil	1,674	0.1	900
Silver	238	419	10,500
Stainless steel	460	14–36	8,020
Styrofoam	1,300	0.003–0.03	50
Teflon TFE	998	0.4	2,100
Tin	226	64	7,300
Tungsten	139	96.6	19,000
Water	4,184	0.6	1,000
Zinc	389	115–125	7,100

Varmeoverføring



- Varme er uspesifikk – uavhengig av hva som skapte den
- Varme kan ikke bevares ett sted – den vil alltid spre seg til omgivelsene
  - Varmeledning
  - Konveksjon
  - Stråling



Varmeledning

Les selv …

- Varmeledningens «Ohms lov»:
- Varmestrøm $H = \frac{dQ}{dt} = -kA\frac{\Delta T}{dx}$
- k = termisk konduktivitet, A = tverrsnitt
- Minus fordi varmen strømmer mot lavere temperatur
- Termisk resistans $r = \frac{L}{k}$
- L er lederens lengde
- Total resistans er r_A+r_C+r_B hvor r_C er den termiske kontakt-resistansen

Ledning ved kontakt og via gass i hulrommet

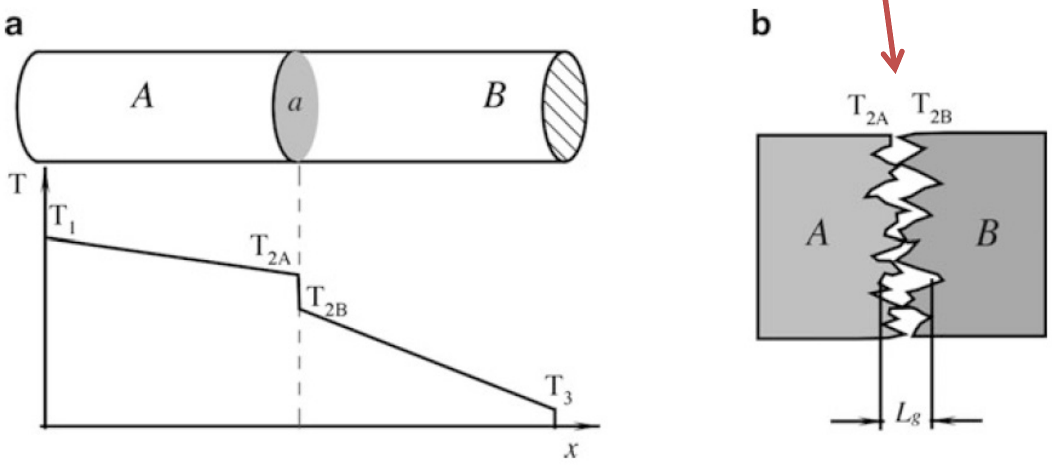
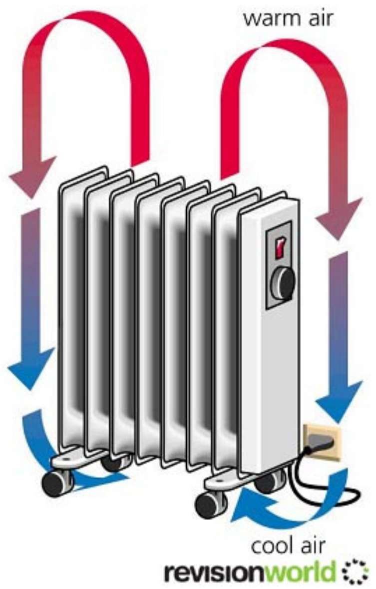
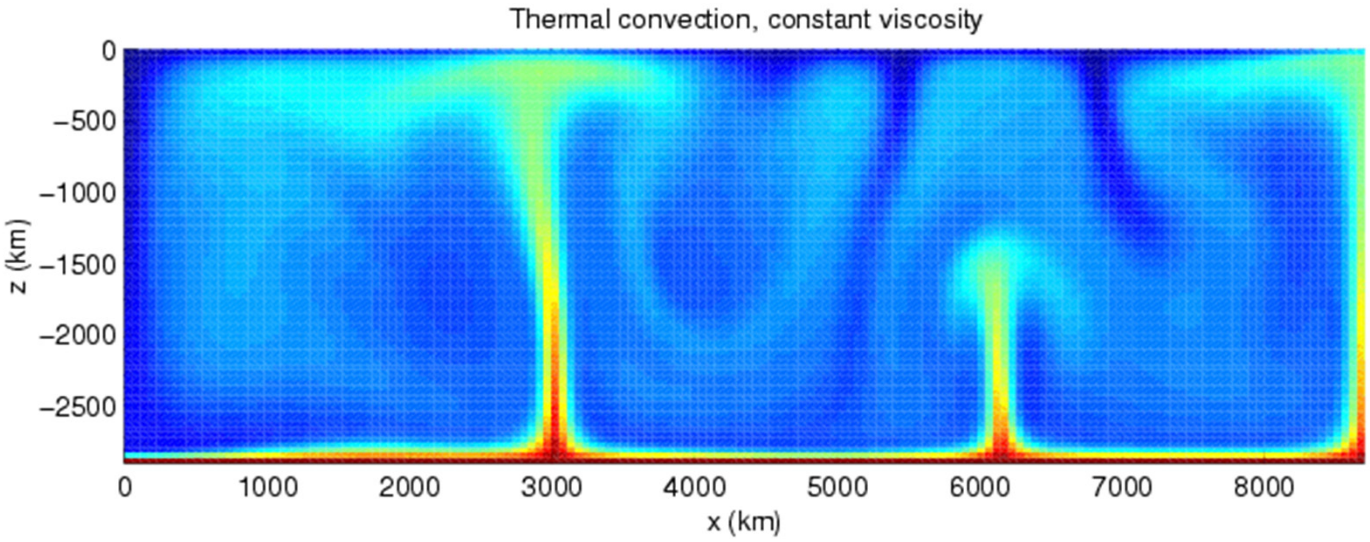


Fig. 3.40 Temperature profile in a joint (**a**) and a microscopic view of a surface contact (**b**)

Konveksjon



- Ledning via gass eller væske
- Naturlig (gravitasjon) eller tvungen (vifte, etc.)
- Varmestrøm $H = \alpha A(T_1 - T_2)$
- α = lokal konveksjonskoeffisient



Varmestråling

- Bølgelengde $\lambda = \frac{c}{v}$
- Sammenhengen mellom T og λ er gitt av Plancks lov (1901) (se boka)
- Wiens lov: $\lambda_m[\mu m] = \frac{2898}{T[K]}$

(viser bølgelengden hvor mesteparten av strålingen er konsentrert)

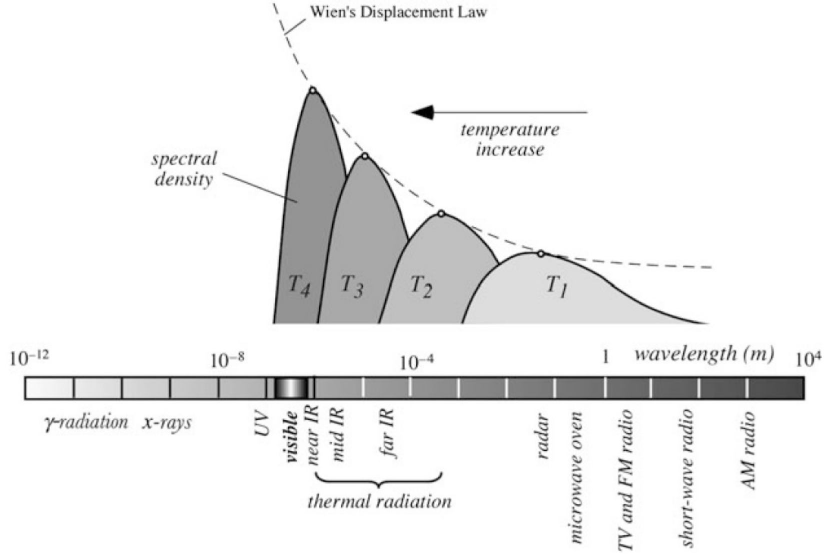
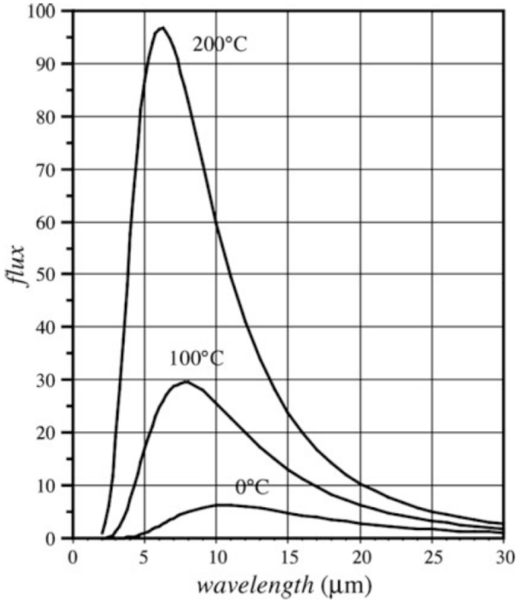
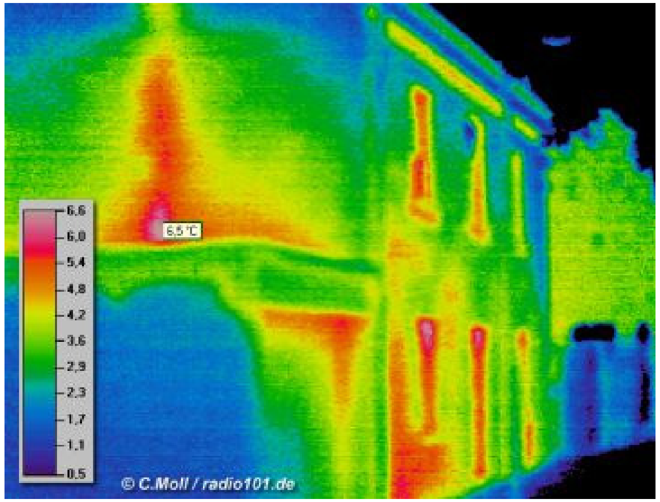


Fig. 3.41 Spectrum of electromagnetic radiation



- Statistisk fordeling av bølgelengder med gjennomsnitt λ_m



Emissivitet

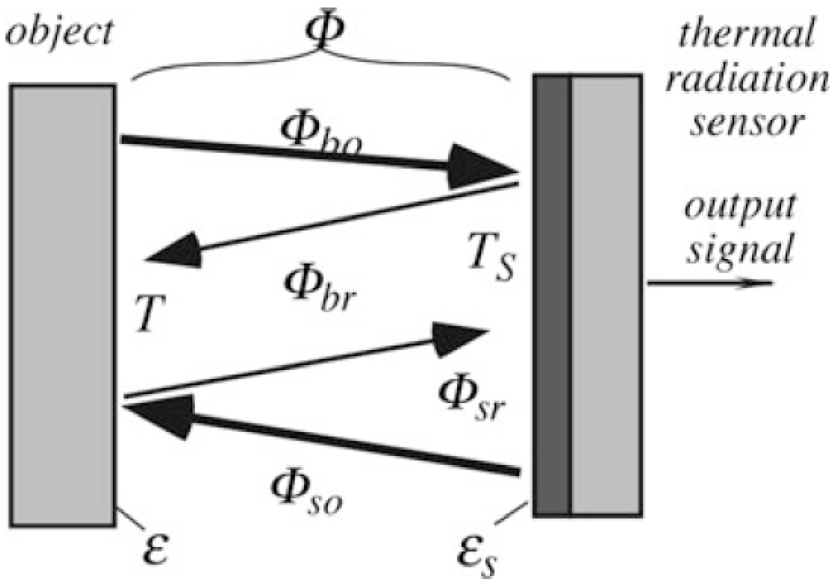
- Emissivitet ε
- Transparens γ
- Reflektivitet ρ
- $\varepsilon + \gamma + \rho = 1$
- Absorptivitet = emissivitet (Kirchhoff, 1860)
- Blackbody: ε ≥ 0.999
- Greybody: ε = 0.98 – 0.99

Netto varmefluks som konverteres av en termisk sensor:

$$\Phi = \Phi_b + \Phi_s = A\varepsilon\varepsilon_s\sigma(T^4 - T_s{}^4)$$

Stefan-Boltzmanns konstant:
$\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4

Fig. 3.43 Thermal radiation exchange between an object and a thermal radiation sensor



Emissivitet

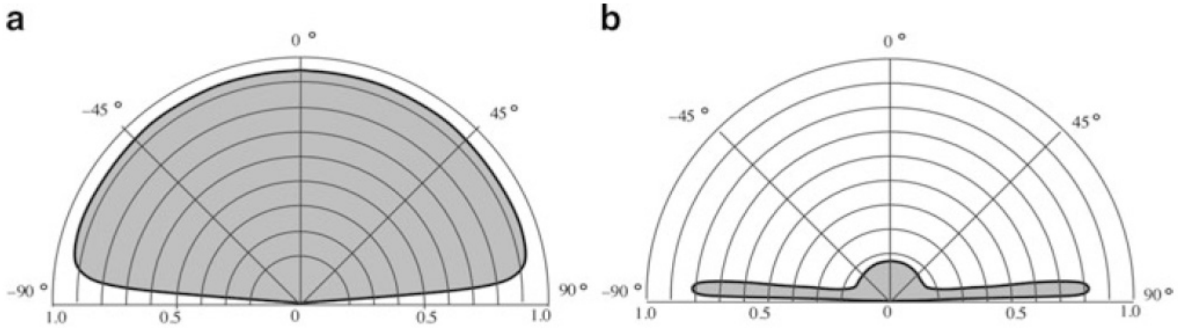


Fig. 3.45 Spatial emissivities for nonmetal (**a**) and a polished metal (**b**)

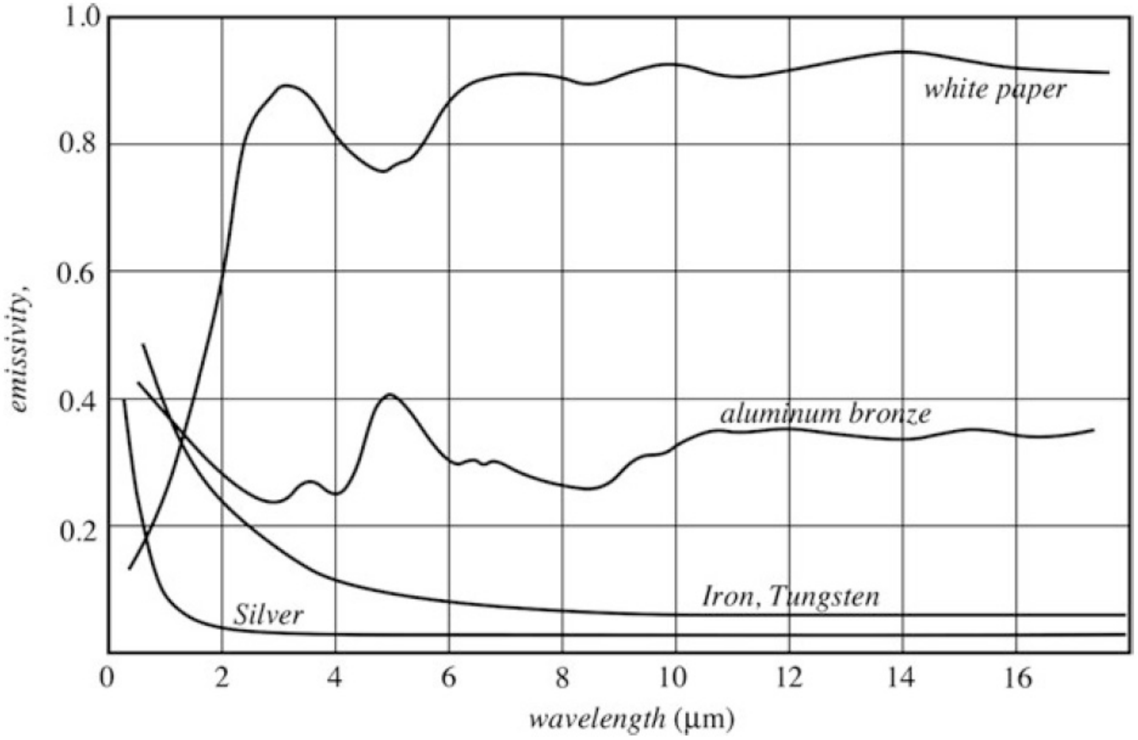
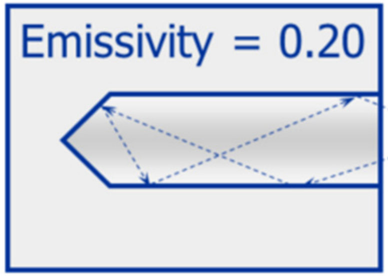


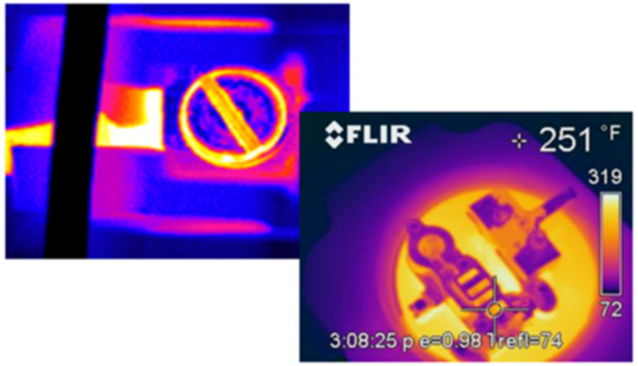
Fig. 3.44 Wavelength dependence of emissivities

Kaviteter

- Elektromagnetisk stråling fra et hulrom gjennom en åpning
- Husk at absorptivitet = emissivitet →

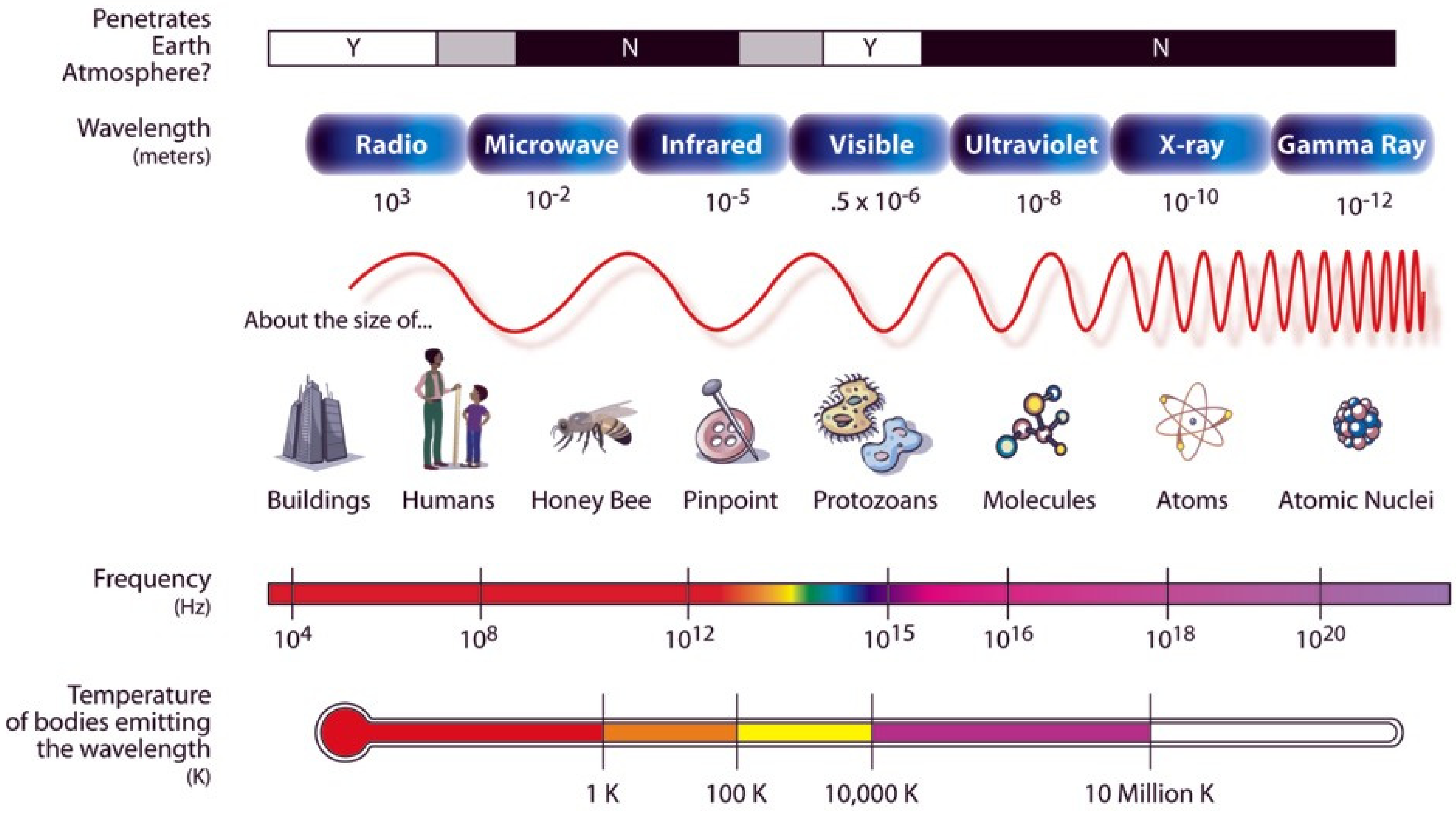


	ρ	ε
#	R	E
1	.80	.20
2	.64	.36
3	.51	.49
4	.41	.59
5	.33	.67
6	.26	.74
7	.21	.79
8	.17	.83



Briller er sorte – de blokkerer MIR og FIR
Rynker ser varmere ut pga. kavitet-effekt

THE ELECTROMAGNETIC SPECTRUM



Lys: 0.1 – 100 μm I vakuum: $c_0 = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 299.792.485,7 \pm 1,1\ [{}^{m}/_{s}]$

Polarisert lys

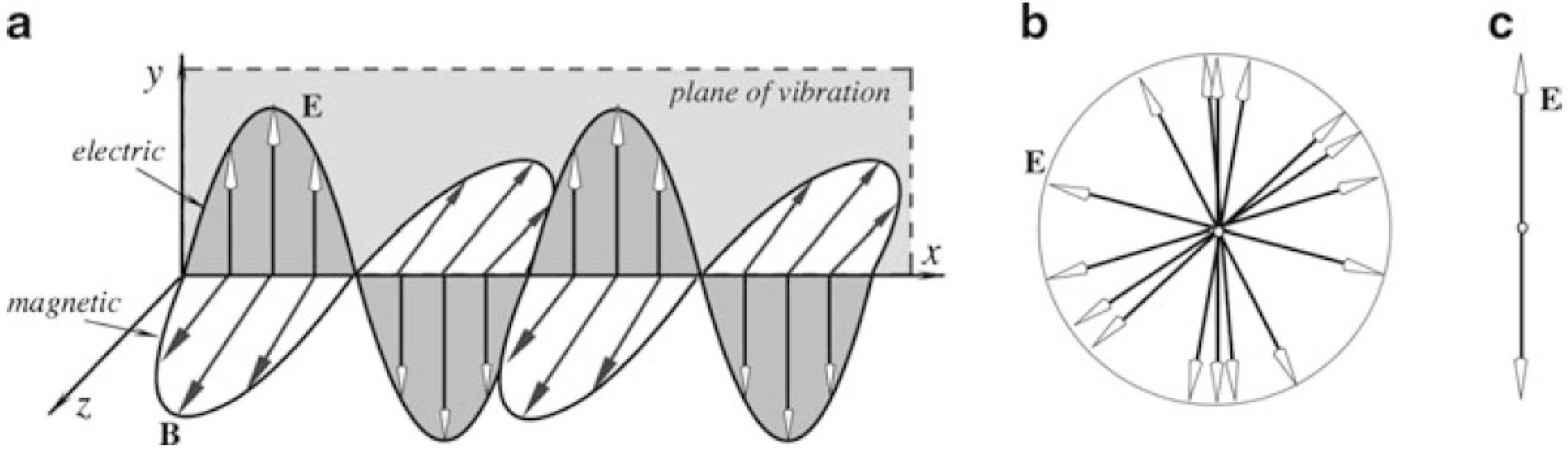


Fig. 3.48 Traveling electromagnetic wave has electric and magnetic field vectors (**a**); unpolarized electric field viewed along the *x*-axis (magnetic vectors are not shown but they are always there) (**b**); vertically polarized electric field (**c**)