1. GAIA

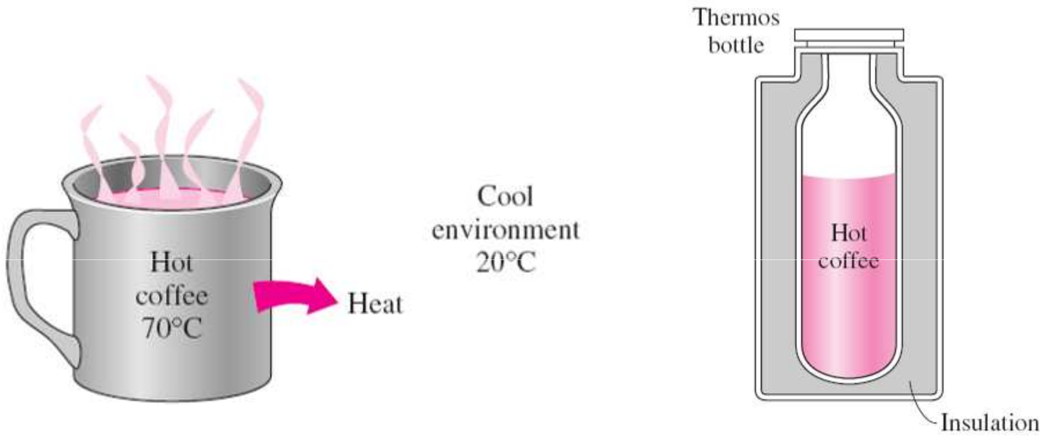
SARRERA ETA OINARRIZKO KONTZEPTUAK

1.0 - HELBURUAK

- **Termodinamikaren** eta **bero-transferentziaren** arteko harremana zein den ulertu
- Energia termikoa bereizi **beste energia mota** batzuetatik, eta bero-transferentzia beste energia-transferentzia batzuetatik
- **Energia-balantze** orokorrak eta gainazalen energia-balantzeak egin
- Bero-transferentziaren oinarrizko mekanismoak, hots, **eroapena**, **konbekzioa** eta **erradiazioa**, ulertu
- Praktikan aldi berean gertatzen diren bero-transferentziako mekanismoak identifikatu
- Bero-galerek eragiten duten **kostuaz** jabetu
- Praktikan aurkitzen diren bero-transferentziako zenbait **problema** ebatzi

1.1 – TERMODINAMIKA ETA BERO TRANSFERENTZIA

TERMODINAMIKA:
Irudiko bi kasuetarako, zein da kafearen oreka-tenperatura?



BERO (ETA MASA) TRANSFERENTZIA:
Oreka-tenperatura heldu arte, zenbat denbora igaroko da ?

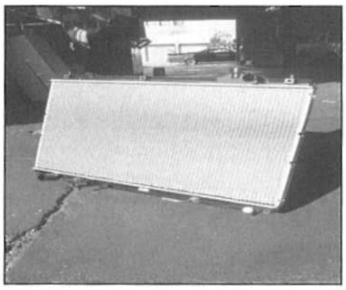
1.1 - TERMODINAMIKA ETA BERO TRANSFERENTZIA

BERO-TRANSFERENTZIAREN APLIKAZIO-EREMUAK


The human body


Air conditioning systems


Airplanes

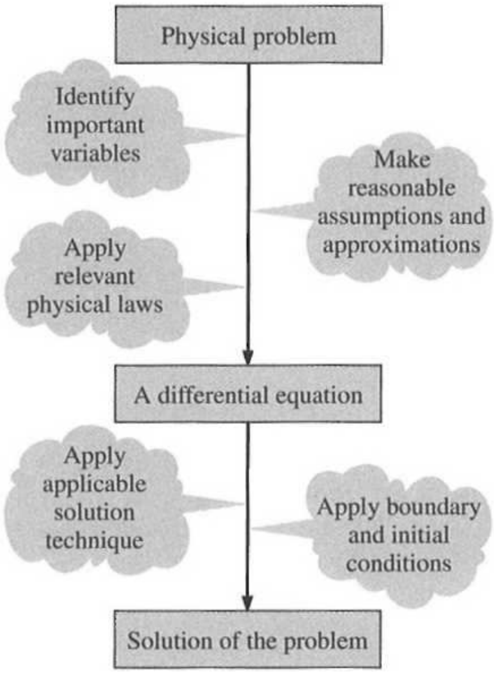

Car radiators

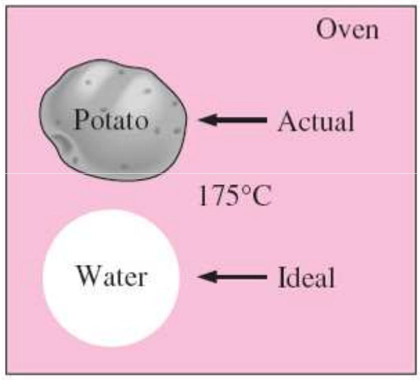

Power plants


Refrigeration systems

1.2 - BERO-TRANSFERENTZIA INGENIARITZAN

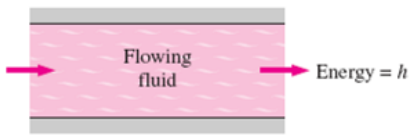
EREDUGINTZA BERO TRANSFERENTZIAN





1.3 - BEROA ETA BESTE ENERGIA MOTA BATZUK

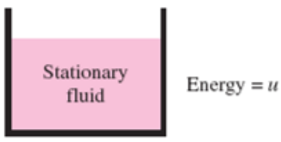
ENTALPÍA: h



FLUXU-ENERGIA

$$h = u + Pv$$

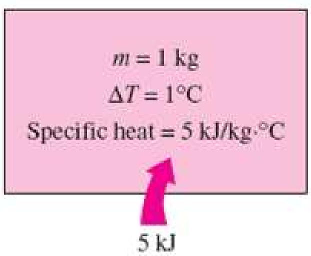
BARNE-ENERGIA: u



GASEN, LIKIDOEN ETA SOLIDOEN BERO ESPEZIFIKOAK

BERO-ESPEZIFIKOA:

- PRESIO KONSTANTEKO BERO-ESPEZIKIFOA : C_p
- BOLUMEN KONSTANTEKO BERO-ESPEZIKIFOA : C_v



• GAS IDEALAK: $Pv = RT$ or $P = \rho RT$

$$C_p = C_v + R$$

• SUBSTANTZIA KONPRIMAEZINAK (solido eta likidoak):

$$C_p \cong C_v \cong C$$

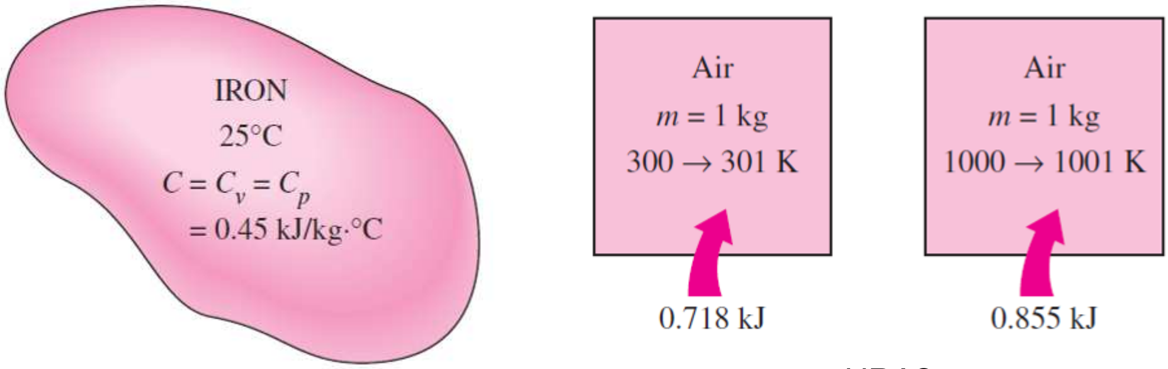
1.3 - BEROA ETA BESTE ENERGIA MOTA BATZUK

GASEN, LIKIDOEN ETA SOLIDOEN BERO ESPEZIFIKOAK

$$1\ \text{kJ/kg}\cdot{}^{\circ}\text{C} \equiv 1\ \text{kJ/kg}\cdot\text{K}$$????????????

$$\Delta u = C_{v,\text{ave}}\Delta T \quad \text{and} \quad \Delta h = C_{p,\text{ave}}\Delta T \qquad \text{(J/g)}$$

$$\Delta U = mC_{v,\text{ave}}\Delta T \quad \text{and} \quad \Delta H = mC_{p,\text{ave}}\Delta T \qquad \text{(J)}$$



¿URA?

1.3 - BEROA ETA BESTE ENERGIA MOTA BATZUK

ENERGIA-TRANSFERENTZIA (ENERGI-KALITATEA)

	MECÁNICA	ELÉCTRICA	CALOR	NUCLEAR, QUÍMICA,…
FUERZA o POTENCIAL	FUERZA [N]	POTENCIAL [V]	DIFERENCIA DE TEMPERATURA [ºC]	
ENERGÍA, TRABAJO o CALOR	POTENCIAL: $m\cdot g\cdot H$ CINÉTICA: $\frac{1}{2}\cdot m\cdot V^2$ [J] = [N·m]	ENERGÍA ELÉCTRICA: E = P·t [J] = [N·m]	CALOR o ENERGÍA INTERCAMBIADA: $Q = \dot{Q}\cdot t$ [J] = [N·m]	
POTENCIA o VELOCIDAD DE TRANSFERENCIA DE CALOR	POTENCIA MECANICA P = F·V P = M·w [W] = [J/s]	POTENCIA ELÉCTRICA P = V·I·cos(φ) [W] = [J/s]	VELOCIDAD DE TRANSFERENCIA DE CALOR $\dot{Q} = f(\Delta T)$ [W] = [J/s]	

¿Cuál de las energías tiene mayor calidad? ¿Como podrías medir la calidad de la energía?

1.3 - BEROA ETA BESTE ENERGIA MOTA BATZUK

ENERGIA-TRANSFERENTZIA

BERO-TRANSFERENTZIA [J] (ELKARTRUKATUTAKO BEROA)

BERO-TRANSFERENTZIOA ABIADURA [W]

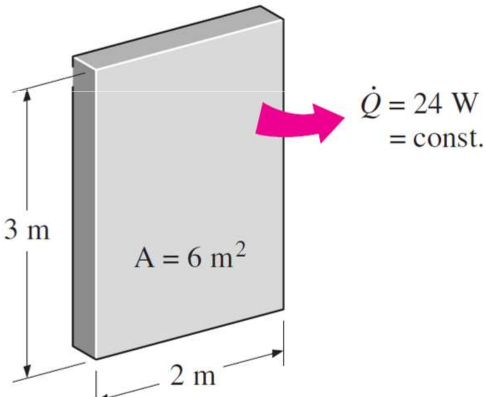
$$Q = \int_0^{\Delta t} \dot{Q}\, dt \qquad \text{(J)}$$

KONSTANTEA [W]

$$Q = \dot{Q}\Delta t \qquad \text{(J)}$$

BERO-FLUXUA [W/m^2]

$$\dot{q} = \frac{\dot{Q}}{A} \qquad (\text{W/m}^2)$$



$$\dot{q} = \frac{\dot{Q}}{A} = \frac{24\ \text{W}}{6\ \text{m}^2} = 4\ \text{W/m}^2$$

1.4 - TERMODINAMIKAREN LEHEN LEGEA

$$\begin{pmatrix}\text{Total energy}\\ \text{entering the}\\ \text{system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{leaving the}\\ \text{system}\end{pmatrix} = \begin{pmatrix}\text{Change in the}\\ \text{total energy of}\\ \text{the system}\end{pmatrix}$$

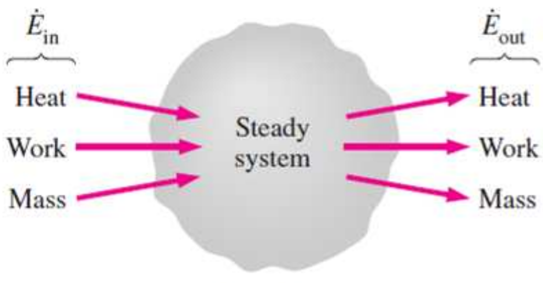
ENERGIAREN KONTSERBAZIO-PRINTZIPIOA

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}} \qquad \text{(J)}$$

ENERGIA-BALANTZEA (DENBORA TARTEA)

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal}\\ \text{kinetic, potential, etc., energies}}} \qquad \text{(W)}$$

POTENTZI-BALANTZEA (ALDIUNEKOA)



$$\dot{E}_{in} = \dot{E}_{out}$$

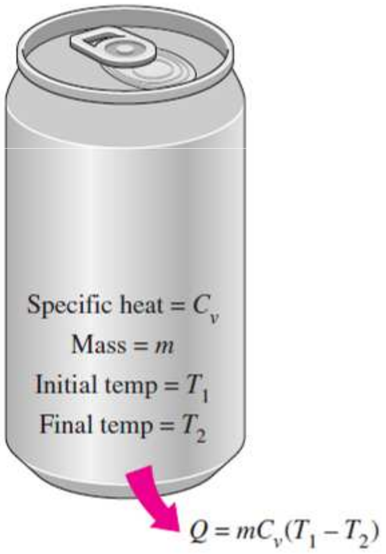
$$(\Delta E_{system} = 0)$$

$$\underbrace{\dot{E}_{in}}_{\substack{\text{Rate of net energy transfer in}\\ \text{by heat, work, and mass}}} = \underbrace{\dot{E}_{out}}_{\substack{\text{Rate of net energy transfer out}\\ \text{by heat, work, and mass}}}$$

$$\underbrace{Q_{\text{in}} - Q_{\text{out}}}_{\substack{\text{Net heat}\\ \text{transfer}}} + \underbrace{E_{\text{gen}}}_{\substack{\text{Heat}\\ \text{generation}}} = \underbrace{\Delta E_{\text{thermal, system}}}_{\substack{\text{Change in thermal}\\ \text{energy of the system}}}$$

BERO-BALANTZEA

ENERGIA-BALANTZEA SISTEMA ITXIETAN



GELDIRIK DAGOEN SISTEMA ITXIA:

$$E_{\text{in}} - E_{\text{out}} = \Delta U = mC_v\Delta T \qquad \text{(J)}$$

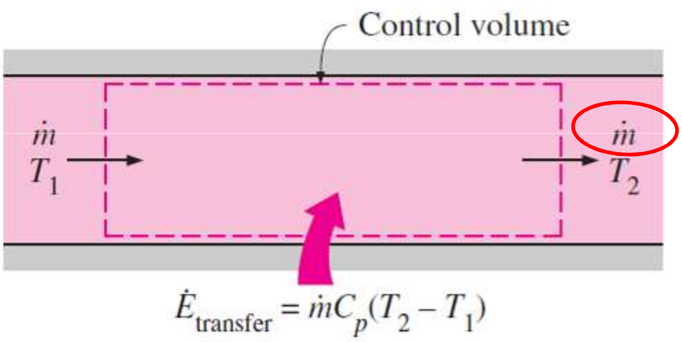
GELDIRIK DAGOEN SISTEMA ITXIA, LANIK EZ:

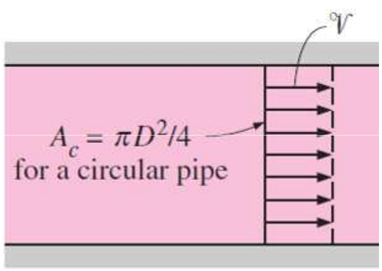
$$Q = mC_v\Delta T \qquad \text{(J)}$$

$$\underbrace{Q_{\text{in}} - Q_{\text{out}}}_{\substack{\text{Net heat}\\ \text{transfer}}} + \underbrace{E_{\text{gen}}}_{\substack{\text{Heat}\\ \text{generation}}} = \underbrace{\Delta E_{\text{thermal, system}}}_{\substack{\text{Change in thermal}\\ \text{energy of the system}}}$$

BERO-BALANTZEA

ENERGIA-BALANTZEA FLUXU GELDIKORREKO SISTEMETAN





$$\dot{Q} = \dot{m}\Delta h = \dot{m}C_p\Delta T \qquad \text{(kJ/s)}$$

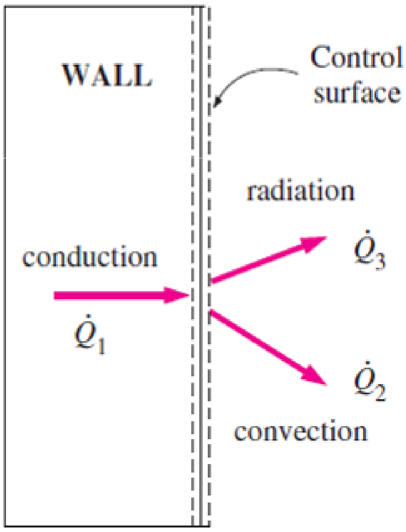
$$\dot{m} = \rho\mathcal{V}A_c \qquad \text{(kg/s)}$$

1.4 - TERMODINAMIKAREN LEHEN LEGEA

$$\underbrace{Q_{in} - Q_{out}}_{\text{Net heat transfer}} + \underbrace{E_{gen}}_{\text{Heat generation}} = \underbrace{\Delta E_{\text{thermal, system}}}_{\text{Change in thermal energy of the system}}$$

BERO-BALANTZEA

GAINAZALEKO ENERGIA-BALANTZEA



$$\dot{Q}_1 = \dot{Q}_2 + \dot{Q}_3$$

1.5 – BERO TRANSFERENTZIAKO MEKANISMOAK

EROAPENA

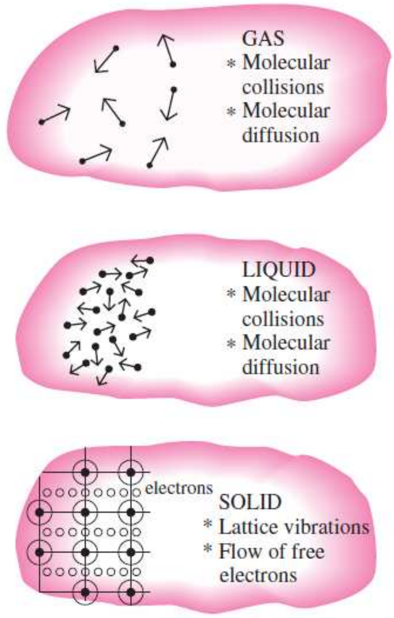
KONBEKZIOA

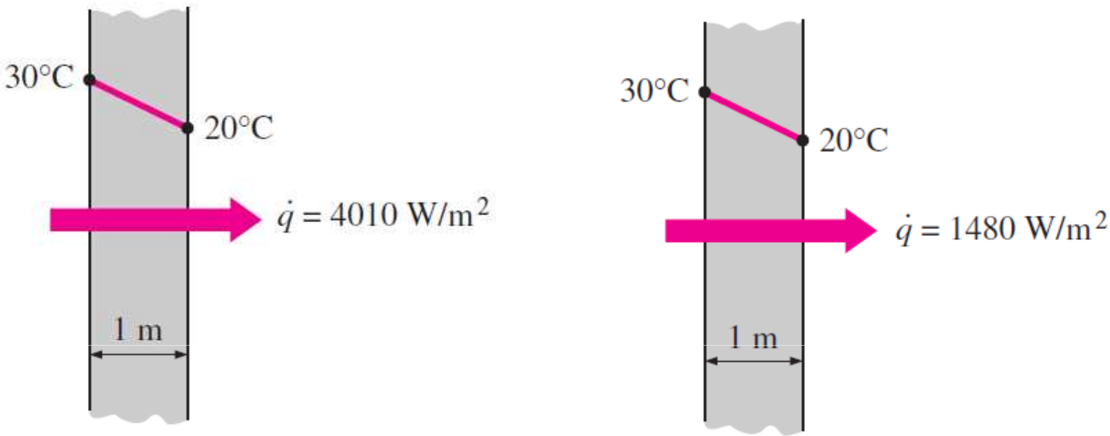
ERRADIAZIOA

Partikulen arteko elkarrekintzen ondorioz substantzia bateko energia handiagoko partikuletatik energia txikiagoko inguruko partikuletara gertatzen den energia-transferentzia, **eroapena** da.

FOURIERREN BERO-EROAPENAREN LEGEA:

$$\dot{Q}_{\text{cond}} = -kA\frac{dT}{dx} \qquad \text{(W)}$$





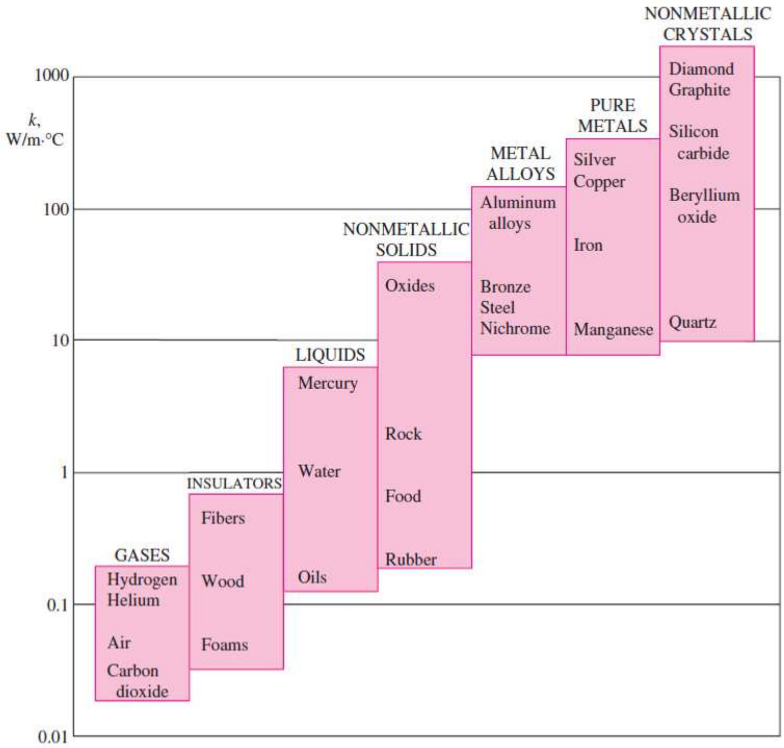
(*a*) Copper (k = 401 W/m·°C)

(*b*) Silicon (k = 148 W/m·°C)

$$\dot{Q}_{\text{cond}} = -kA\frac{dT}{dx} \quad \Rightarrow \quad \dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x} \qquad \text{(W)}$$

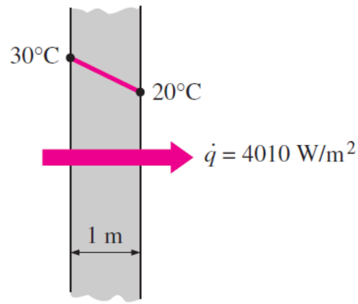
¿UNITATEAK?

EROANKORTASUN TERMIKOA



$$\dot{Q}_{cond} = -kA\frac{dT}{dx} \quad (W)$$

$$\dot{Q}_{cond} = kA\frac{T_1 - T_2}{\Delta x} \quad (W)$$



(*a*) Copper (k = 401 W/m·°C)

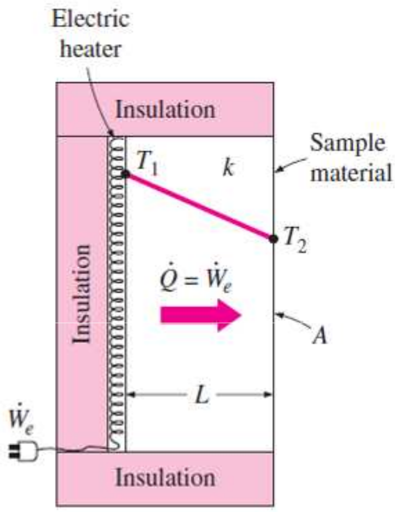
EROANKORTASUN TERMIKOA

The thermal conductivities of some materials at room temperature

Material	k, W/m · °C*
Diamond	2300
Silver	429
Copper	401
Gold	317
Aluminum	237
Iron	80.2
Mercury (l)	8.54
Glass	0.78
Brick	0.72
Water (l)	0.613
Human skin	0.37
Wood (oak)	0.17
Helium (g)	0.152
Soft rubber	0.13
Glass fiber	0.043
Air (g)	0.026
Urethane, rigid foam	0.026

*Multiply by 0.5778 to convert to Btu/h · ft · °F.

$$\dot{Q}_{cond} = -kA\frac{dT}{dx}$$

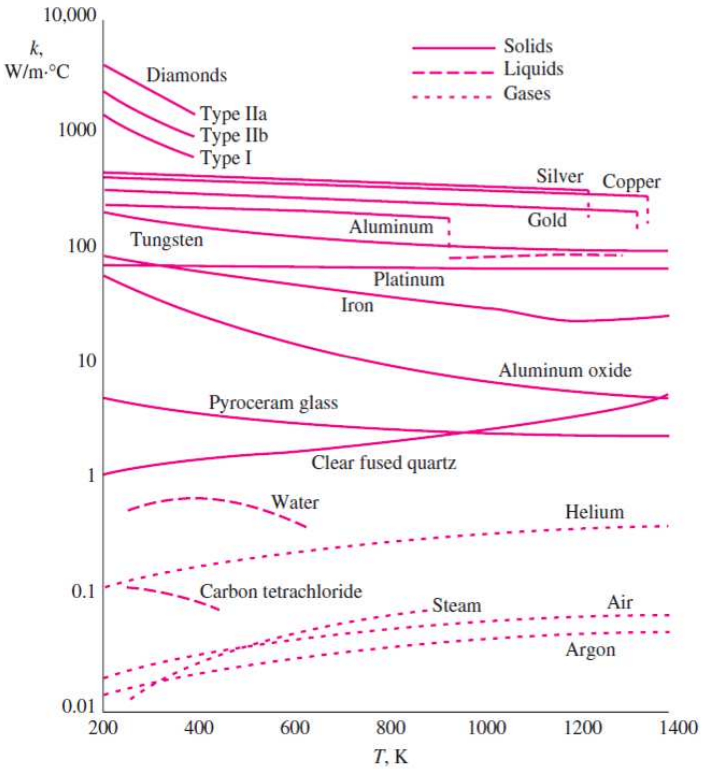


$$k = \frac{L}{A(T_1 - T_2)}\dot{Q}$$

$$\dot{Q}_{cond} = kA\frac{T_1 - T_2}{\Delta x}$$

EROANKORTASUN TERMIKOA

$$\dot{Q}_{\text{cond}} = -kA\frac{dT}{dx}$$



Thermal conductivities of materials vary with temperature

T, K	Copper	Aluminum
100	482	302
200	413	237
300	401	237
400	393	240
600	379	231
800	366	218

The thermal conductivity of an alloy is usually much lower than the thermal conductivity of either metal of which it is composed

Pure metal or alloy	k, W/m · °C, at 300 K
Copper	401
Nickel	91
Constantan (55% Cu, 45% Ni)	23
Copper	401
Aluminum	237
Commercial bronze (90% Cu, 10% Al)	52

DIFUSIBITATE TERMIKOA

$$\alpha = \frac{\text{Heat conducted}}{\text{Heat stored}} = \frac{k}{\rho C_p} \qquad (\text{m}^2/\text{s})$$

BERO-DIFUSIOA MATERIALETAN ZENBATEKO ABIDURAZ GERTATZEN DEN ADIERAZTEN DU

The thermal diffusivities of some materials at room temperature

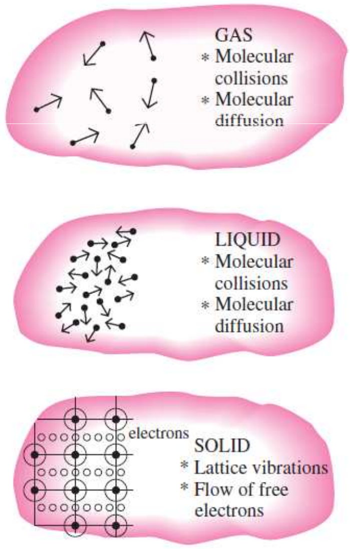
Material	α, m^2/s*
Silver	149×10^{-6}
Gold	127×10^{-6}
Copper	113×10^{-6}
Aluminum	97.5×10^{-6}
Iron	22.8×10^{-6}
Mercury (l)	4.7×10^{-6}
Marble	1.2×10^{-6}
Ice	1.2×10^{-6}
Concrete	0.75×10^{-6}
Brick	0.52×10^{-6}
Heavy soil (dry)	0.52×10^{-6}
Glass	0.34×10^{-6}
Glass wool	0.23×10^{-6}
Water (l)	0.14×10^{-6}
Beef	0.14×10^{-6}
Wood (oak)	0.13×10^{-6}

*Multiply by 10.76 to convert to ft^2/s.

Gainazal solido baten eta haren inguruan mugimenduan dagoen likido edo gasaren artean energia transferitzeko modua, eta eroapenaren eta fluido-mugimenduaren efektuen konbinazioa da, **konbekzioa** da.

NEWTONEN HOZTE-LEGEA

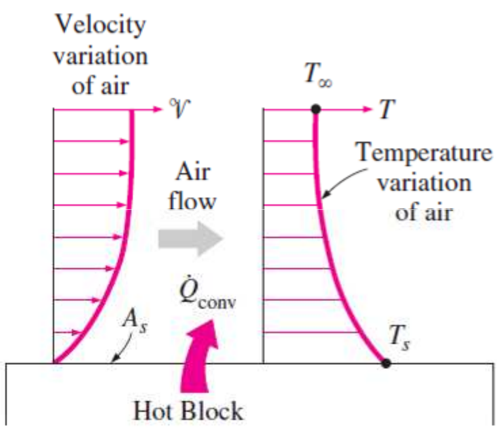
$$\dot{Q}_{\text{conv}} = hA_s\,(T_s - T_\infty) \qquad \text{(W)}$$

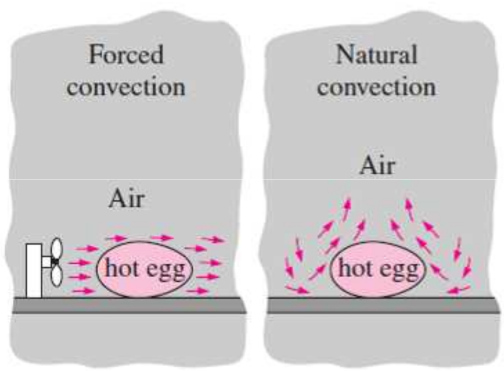


Fluidoaren mugimendu globalik gabe, gainazal solidoaren eta inguruko fluidoaren arteko bero-transferentzia eroapen hutsekoa da.

$$\dot{Q}_{\text{conv}} = hA_s\,(T_s - T_\infty) \qquad \text{(W)}$$

KONBEKZIO KOEFIZIENTEA





1.7 - KONBEKZIOA

$$\dot{Q}_{\text{conv}} = hA_s(T_s - T_\infty) \qquad \text{(W)}$$

KONBEKZIO KOEFIZIENTEA

Typical values of convection heat transfer coefficient

Type of convection	h, W/m^2 · °C*
Free convection of gases	2–25
Free convection of liquids	10–1000
Forced convection of gases	25–250
Forced convection of liquids	50–20,000
Boiling and condensation	2500–100,000

*Multiply by 0.176 to convert to Btu/h · ft^2 · °F.

ZEREN MENPEKOA DA ?

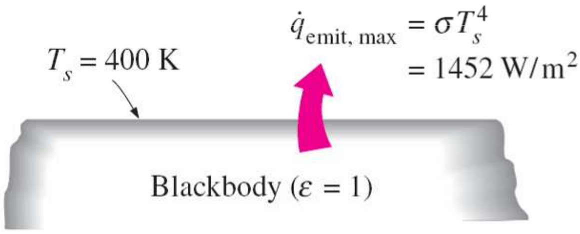
- LIKIDO vs GAS
- BEHARTUA vs NATURALA
- SOLIDOAREN ITXURA
- SOLIDOAREN POSIZIOA
- …

1.8 - ERRADIAZIOA

Materiak, atomoen edo molekulen konfigurazio elektronikoaren aldaketen ondorioz, uhin elektromagnetiko (edo fotoi) moduan igortzen duen energia. **erradiazioa** da.

STEFAN-BOLTZMANNEN LEGEA:

$$\dot{Q}_{\text{emit, max}} = \sigma A_s T_s^4 \qquad \text{(W)}$$



Eroapenak eta konbekzioak ez bezala, erradiazio bidezko bero-transferentziak ez du behar bitartekorik. Izatez, erradiazio bidezko bero-transferentzia lasterragoa da (argiaren abiadura du), eta ez da moteltzen hutsean.

1.8 - ERRADIAZIOA

$$\dot{Q}_{\text{emit, max}} = \sigma A_s T_s^4 \rightarrow \dot{Q}_{\text{emit}} = \varepsilon\sigma A_s T_s^4 \qquad \text{(W)}$$

EMISIBITATEA

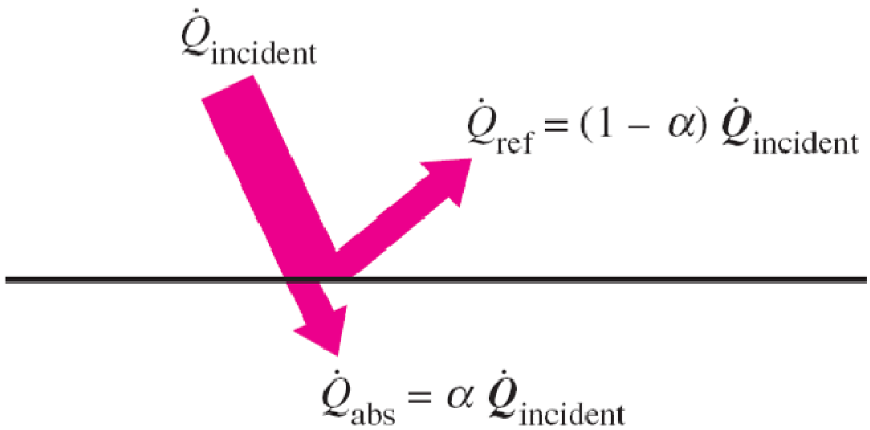
Emissivities of some materials at 300 K

Material	Emissivity
Aluminum foil	0.07
Anodized aluminum	0.82
Polished copper	0.03
Polished gold	0.03
Polished silver	0.02
Polished stainless steel	0.17
Black paint	0.98
White paint	0.90
White paper	0.92–0.97
Asphalt pavement	0.85–0.93
Red brick	0.93–0.96
Human skin	0.95
Wood	0.82–0.92
Soil	0.93–0.96
Water	0.96
Vegetation	0.92–0.96

1.8 - ERRADIAZIOA

$$\dot{Q}_{\text{absorbed}} = \alpha \dot{Q}_{\text{incident}} \qquad \text{(W)}$$

ABSORTIBITATEA, ISLADAPENA ETA (TRANSMISIBITATEA)



1.8 - ERRADIAZIOA

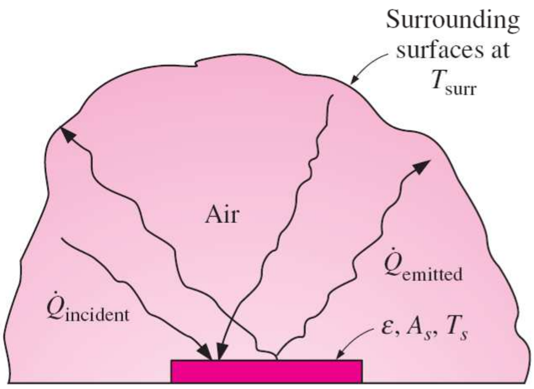
ERRADIAZIO BIDEZKO BERO-TRANSFERENTZIA:
Xurgatu eta emititu arteko diferentzia

$$\dot{Q}_{emit} = \varepsilon \sigma A_s T_s^4 \qquad \text{(W)}$$

$$\dot{Q}_{absorbed} = \alpha \dot{Q}_{incident} \qquad \text{(W)}$$

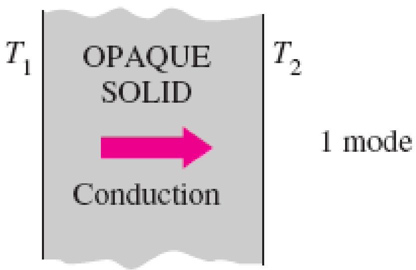
KIRCHOFFEN LEGEA

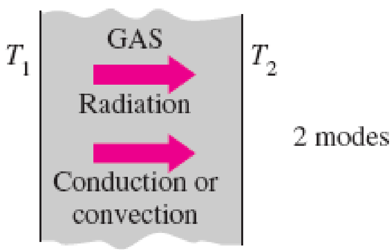
$$\dot{Q}_{rad} = \varepsilon \sigma A_s (T_s^4 - T_{surr}^4) \qquad \text{(W)}$$

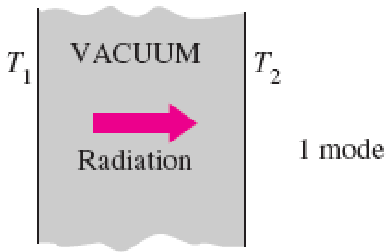


$$\dot{Q}_{rad} = \varepsilon \sigma A_s (T_s^4 - T_{surr}^4)$$

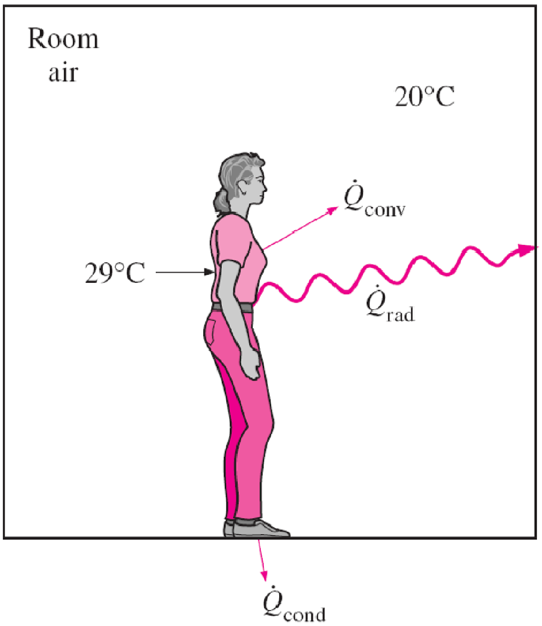
1.9 - ALDIBEREKO BERO-TRANSFERENTZIAKO MEKANISMOAK







1. ADIBIDEA – Pertsona baten bero-galerak



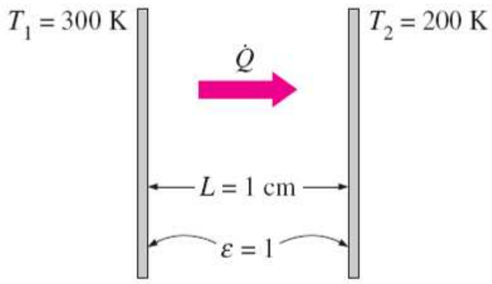
$\varepsilon = 0.95$

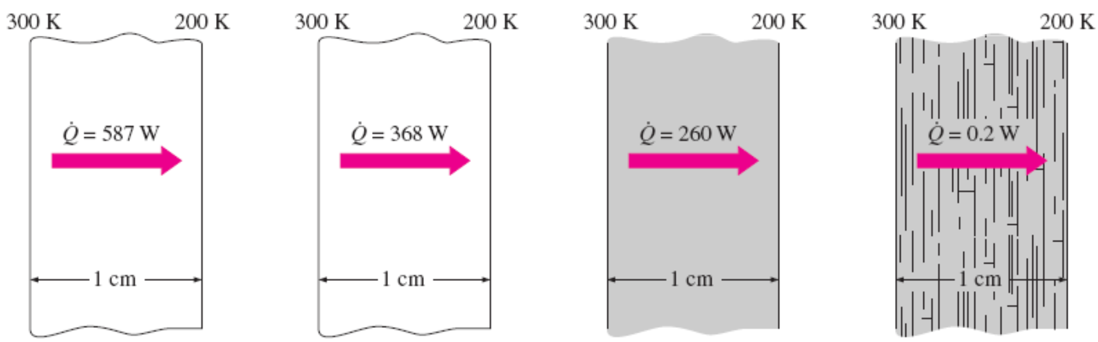
$$\dot{Q}_{conv} = hA_s(T_s - T_\infty) = (6\ \mathrm{W/m^2 \cdot {}^\circ C})(1.6\ \mathrm{m^2})(29 - 20)^\circ\mathrm{C} = 86.4\ \mathrm{W}$$

$$\dot{Q}_{rad} = \varepsilon\sigma A_s(T_s^4 - T_{surr}^4) = (0.95)(5.67 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4})(1.6\ \mathrm{m^2}) \times [(29 + 273)^4 - (20 + 273)^4]\ \mathrm{K^4} = 81.7\ \mathrm{W}$$

$$\dot{Q}_{total} = \dot{Q}_{conv} + \dot{Q}_{rad} = (86.4 + 81.7)\ \mathrm{W} = 168.1\ \mathrm{W}$$

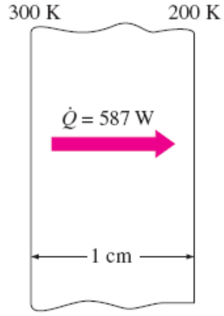
2. ADIBIDEA – Bi xafla isotermikoren arteko bero-transferentzia





(*a*) Air space (*b*) Vacuum (*c*) Insulation (*d*) Superinsulation

2. ADIBIDEA – Bi xafla isotermikoren arteko bero-transferentiza

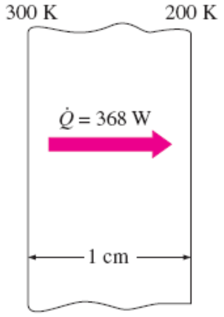


(*a*) Air space

$$\dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{L} = (0.0219\ \text{W/m}\cdot{}^\circ\text{C})(1\ \text{m}^2)\frac{(300 - 200)^\circ\text{C}}{0.01\ \text{m}} = 219\ \text{W}$$

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A(T_1^4 - T_2^4) = (1)(5.67 \times 10^{-8}\ \text{W/m}^2\cdot\text{K}^4)(1\ \text{m}^2)[(300\ \text{K})^4 - (200\ \text{K})^4] = 368\ \text{W}$$

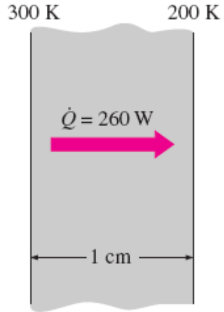
$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{cond}} + \dot{Q}_{\text{rad}} = 219 + 368 = 587\ \text{W}$$



(*b*) Vacuum

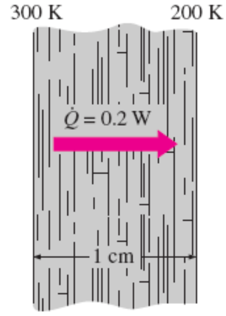
$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{rad}} = 368\ \text{W}$$

2. ADIBIDEA – Bi xafla isotermikoren arteko bero-transferentiza



(*c*) Insulation

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{cond}} = kA\frac{T_1 - T_2}{L} = (0.026\ \text{W/m}\cdot{}^\circ\text{C})(1\ \text{m}^2)\frac{(300 - 200)^\circ\text{C}}{0.01\ \text{m}} = 260\ \text{W}$$



(*d*) Superinsulation

$$\dot{Q}_{\text{total}} = kA\frac{T_1 - T_2}{L} = (0.00002\ \text{W/m}\cdot{}^\circ\text{C})(1\ \text{m}^2)\frac{(300 - 200)^\circ\text{C}}{0.01\ \text{m}} = 0.2\ \text{W}$$

1.10 – IRAKATSIKO EZ DIREN ATALAK

- 1.1eko azpiatala: AURREKARI HISTORIKOAK

Irudi iturria:
ÇENCEL, Y.A. TRANSFERENCIA DE CALOR Y MASA, Un enfoque práctico. McGraw-Hil.3 Edición. 2007