Heat and Mass Transfer

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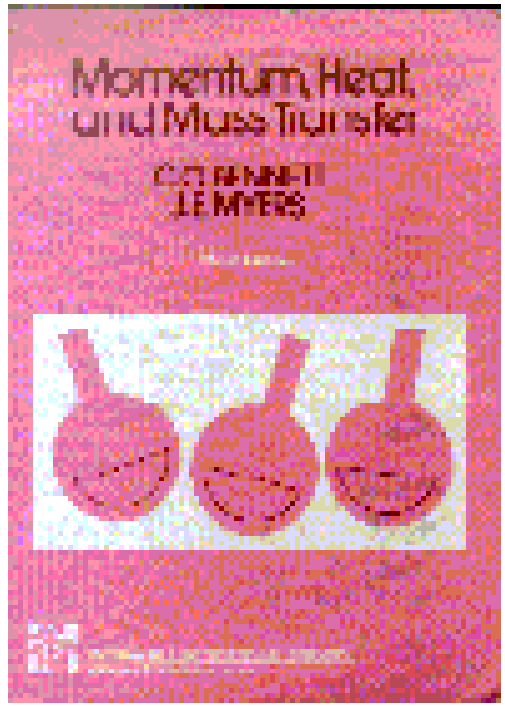
Textbook

Momentum, Heat and Mass Transfer

by C. O. O. Bennett,J. E. Myers,J.E. Meyers

Edition:3 Pages:848 Book Format:Hardcover ISBN:0070046719

Date Published:01/1982 Publisher:McGraw-Hill Higher Education



Lecture Schedule

Heat Transfer

Week 1	Introduction (16)
Week 2	Conduction and Thermal Conductivity (17)
Week 3	Steady-State Heat Conduction (18)
Week 4	Unsteady-State Heat Conduction (19)
	Quiz #1 (9/21)
Week 5	Numerical Analysis in Heat Conduction (20)
Week 6	Convective Heat-Transfer Coefficients (21)
Week 7	Heat Transfer with Laminar Flow (22)
Week 8	Heat Transfer with Turbulent Flow (23)
Week 9	**Midterm Exam (10/31)**
Week 10	Design Equations for Convective Heat Transfer
Week 11	Boiling and Condensation
Week 12	Radiant Heat Transfer
	Quiz #2 (11/23)
Week 13	Heat Exchange Equipment

Mass Transfer

Week 14	Molecular Diffusion and Diffusivity
Week 15	Convective Mass-Transfer Coefficients
Week 16	Analogy of Heat and Mass Transfer
	Final Exam (12/7)

Syllabus

Quizzes, Midterm and Final [7:00-9:00 pm, Rm 302-509]

Quizzes will be closed book.

Midterm and Final Exams will be open book.

Only your text and a calculator will be allowed for the exams.

In general, exams cannot be made-up.

Homework

The homework is due at the beginning of the class on the day the assignment is due.

The late homework sets will be accepted (but the lower grade for the later homework).

Syllabus

Grading

Attendance	:	5 %
Homework	:	15 %
Quiz #1	:	10 %
Midterm exam	:	20 %
Quiz #2	:	10 %
Final exam	:	30 %
Design Project	:	10 %
Total	:	100 %

Grade Scale

A: 25%, B:30%, C or below 45%

Repeaters will be scaled separately follow the above scale

출석부 작성

성명, 사진, 학번, 전화번호, 이메일주소 명시하여 이메일로 제출

Due date : 2006. 9. 8

Where to submit: likewind@snu.ac.kr

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INTRODUCTION TO HEAT TRANSFER

History of Heat Transfer Study

1593	**Galileo Galilei:**	The first thermometer, a device where the expansion of air was used as a measure of temperature
1612	**Santorio Santorio:**	The first inventor to put a numerical scale on the instrument.
1724	**Daniel Gabriel Fahrenheit :**	The first mercury thermometer
1742	**Anders Celcius :**	devised the centigrade scale or "Celsius scale" of temperature
1757	**Franklin :**	A series of observations on the thermal conductivity of metallic, ceramic, and wooden materials with reference to teapot handle
18th C	**Newton :**	The rate of cooling of a body was proportional to the temperature difference between the body and its surroundings, a relation which was true within the limits of experimental accuracy attainable in the 18th century.
	Scheele : (1724-1786)	Heat from a stove could move through air without warming itself but could be absorbed by glass. He proposed that heat transferred in this fashion be called radiant heat
1848	**William Thomson: Kelvin**	Lord Kelvin took the whole process one step further with his invention of the Kelvin Scale in 1848. The Kelvin Scale measures the ultimate extremes of hot and cold. Kelvin developed the idea of absolute temperature, what is called the "Second Law of Thermodynamics", and developed the dynamical theory of heat.

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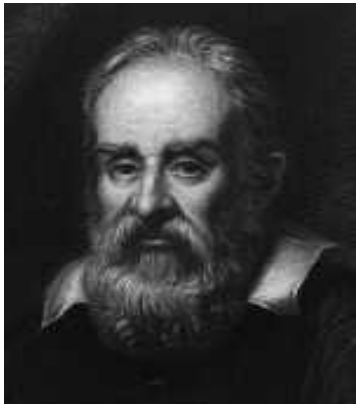
Galileo Galilei



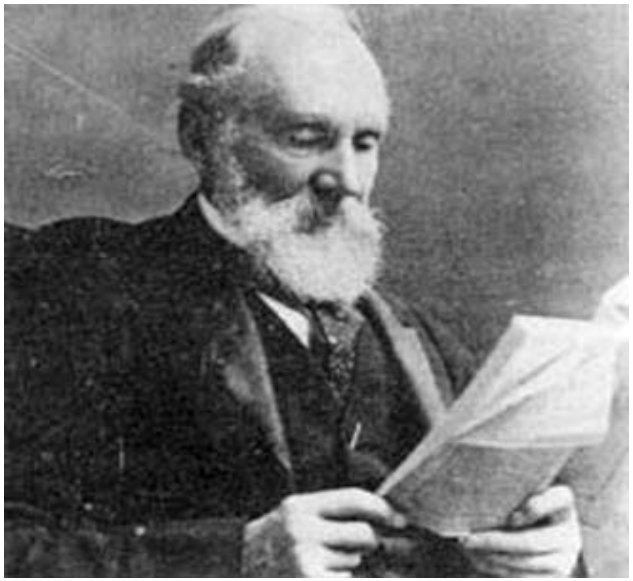
Galileo Galilei was born in Pisa, Italy on February 15, 1564. He was the first of 7 children. Although his father was a musician and wool trader, he wanted his clearly talented son to study medicine as there was more money in medicine. So, at age eleven, Galileo was sent off to study in a Jesuit monastery.

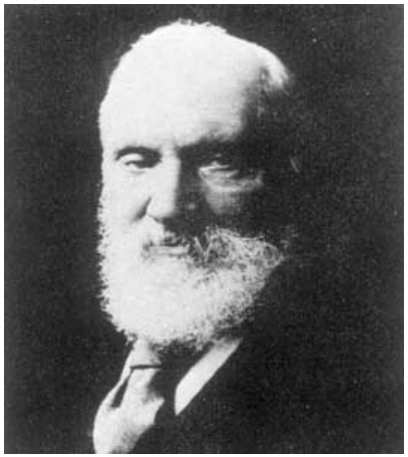
Daniel Gabriel Fahrenheit

Gabriel Fahrenheit
1686--1736

Daniel Gabriel Fahrenheit (1686-1736) was the German physicist who invented the alcohol thermometer in 1709, and the mercury thermometer in 1714. In 1724, he introduced the temperature scale that bears his name - Fahrenheit Scale

Lord William Thomson Kelvin





Lord Kelvin took the whole process one step further with his invention of the Kelvin Scale in 1848. The Kelvin Scale measures the ultimate extremes of hot and cold. Kelvin developed the idea of absolute temperature, what is called the "Second Law of Thermodynamics", and developed the dynamical theory of heat.

Sir William Thomson, Baron Kelvin of Largs, Lord Kelvin of Scotland (1824 - 1907) studied at Cambridge University, was a champion rower, and later became a Professor of Natural Philosophy at the University of Glasgow. Among his other achievements was the 1852 discovery of the "Joule-Thomson Effect" of gases and his work on the first transatlantic telegraph cable (for which he was knighted), and his inventing of the mirror galvanometer used in cable signaling, the siphon recorder, the mechanical tide predictor, an improved ship's compass.

Anders Celsius

1701-1744

Celsius thermometer made by J.G. Hasselström, Stockholm, late 18th century.

Anders Celsius was born in Uppsala, Sweden in 1701. He devised the centigrade scale or "Celsius scale" of temperature in 1742.

Anders Celsius should be recognized as the first to perform and publish careful experiments aiming at the definition of an international temperature scale on scientific grounds. In his Swedish paper "Observations of two persistent degrees on a thermometer" he reports on experiments to check that the freezing point is independent of latitude (and also of atmospheric pressure!). He determined the dependence of the boiling of water with atmospheric pressure (in excellent agreement with modern data). He further gave a rule for the determination of the boiling point if the barometric pressure deviates from a certain standard pressure.

The Celsius temperature scale is also referred to as the "centigrade" scale. Centigrade means "consisting of or divided into 100 degrees". The Celsius scale has 100 degrees between the freezing point (0 C) and boiling point (100 C) of pure water at sea level air pressure. The term "Celsius" was adopted in 1948 by an international conference on weights and measures.

Galileo thermometer

Based on a thermoscope invented by Galileo Galilei in the early 1600s, the thermometer on your co-worker's desk is called a **Galileo thermometer**. A simple, fairly accurate thermometer, today it is mostly used as decoration. The Galileo thermometer consists of a sealed glass tube that is filled with water and several floating bubbles. The bubbles are glass spheres filled with a colored liquid mixture. This liquid mixture may contain alcohol, or it might simply be water with food coloring.

Attached to each bubble is a little metal tag that indicates a temperature.The concept is : Each liquid changes the specific gravity by changing by the temperature. If the temperature falls – gets colder – then the bubble rise up - if the temperature gets hotter then the bubbles fall. The bubble that is the lowest floating – at the upper part – shows the present temperature.

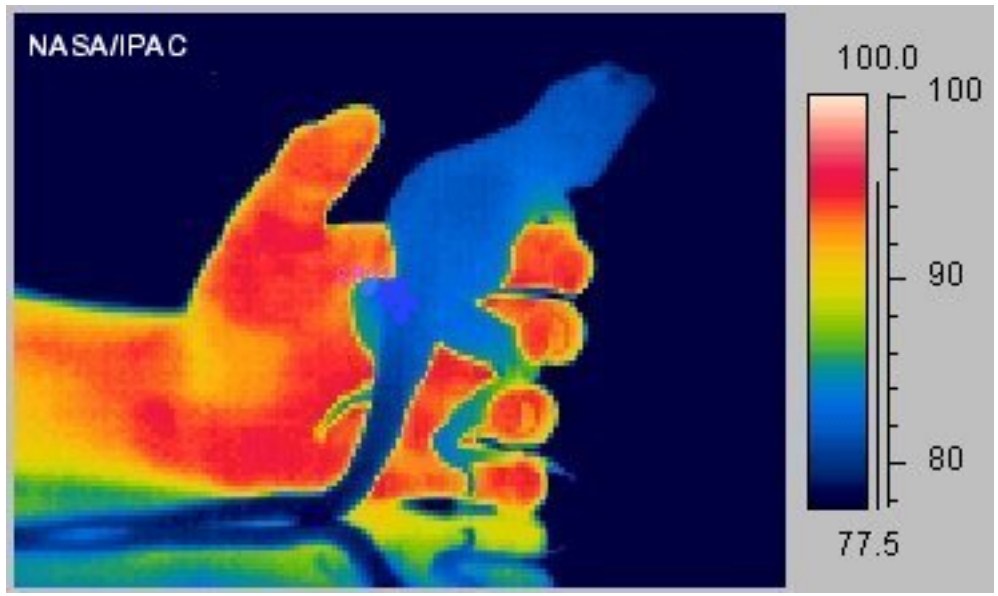
Ear Thermometer

Pioneering biodynamicist and flight surgeon with the Luftwaffe during World War II, Theodore Hannes Benzinger invented the ear thermometer.

David Phillips invented the infra-red ear thermometer in 1984.

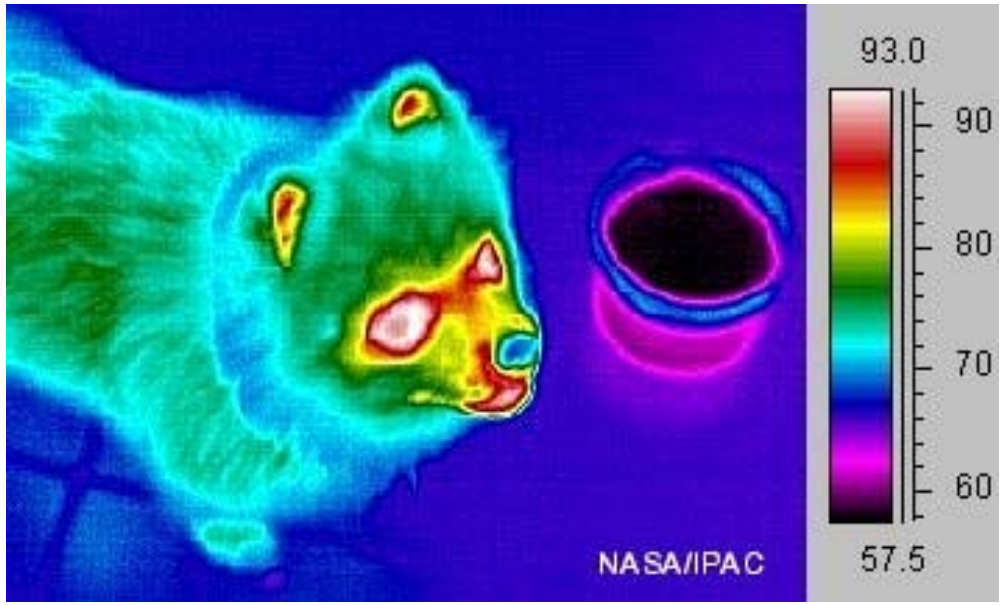
Dr. Jacob Fraden, CEO of Advanced Monitors Corporation, invented the world's best-selling ear thermometer, the Thermoscan® Human Ear

Infra Red Thermometer



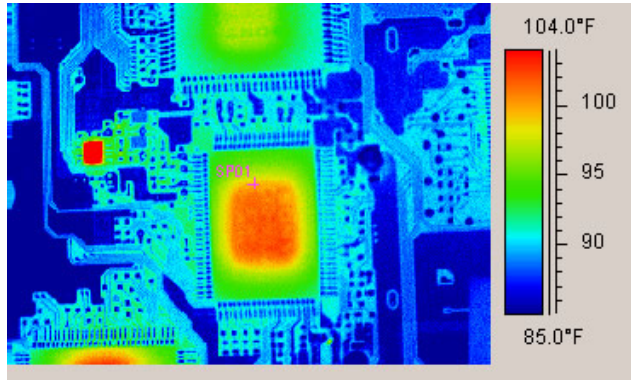
Lizards are cold-blooded and their body temperature are close to that of their environment. Notice the difference in temperature between the cool lizard and the warm human hand. The lizard is a bit warmer than room temperature due to heat from the human hand holding it.

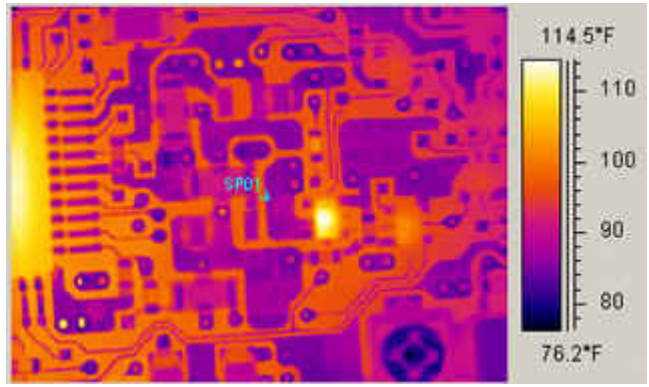
Infrared (IR) Thermometer

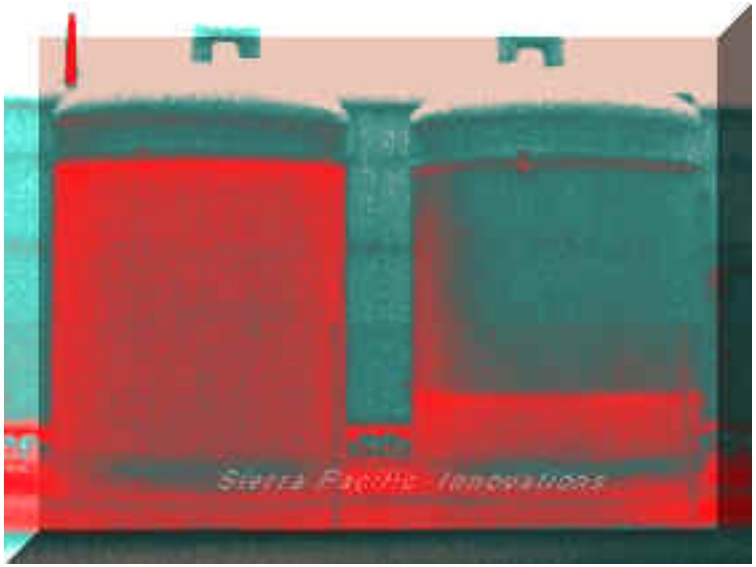


This warm-blooded dog is covered with a thick coat of fur which prevents much the heat generated by his body from escaping. In the infrared we can see how areas of the dog which are covered by thicker fur are cooler, while areas not covered much fur, like eyes, ears and mouth (when open) glow brightly in the infrared. Notice how cool the dog's nose is! You can also see the dog's cool water dish.

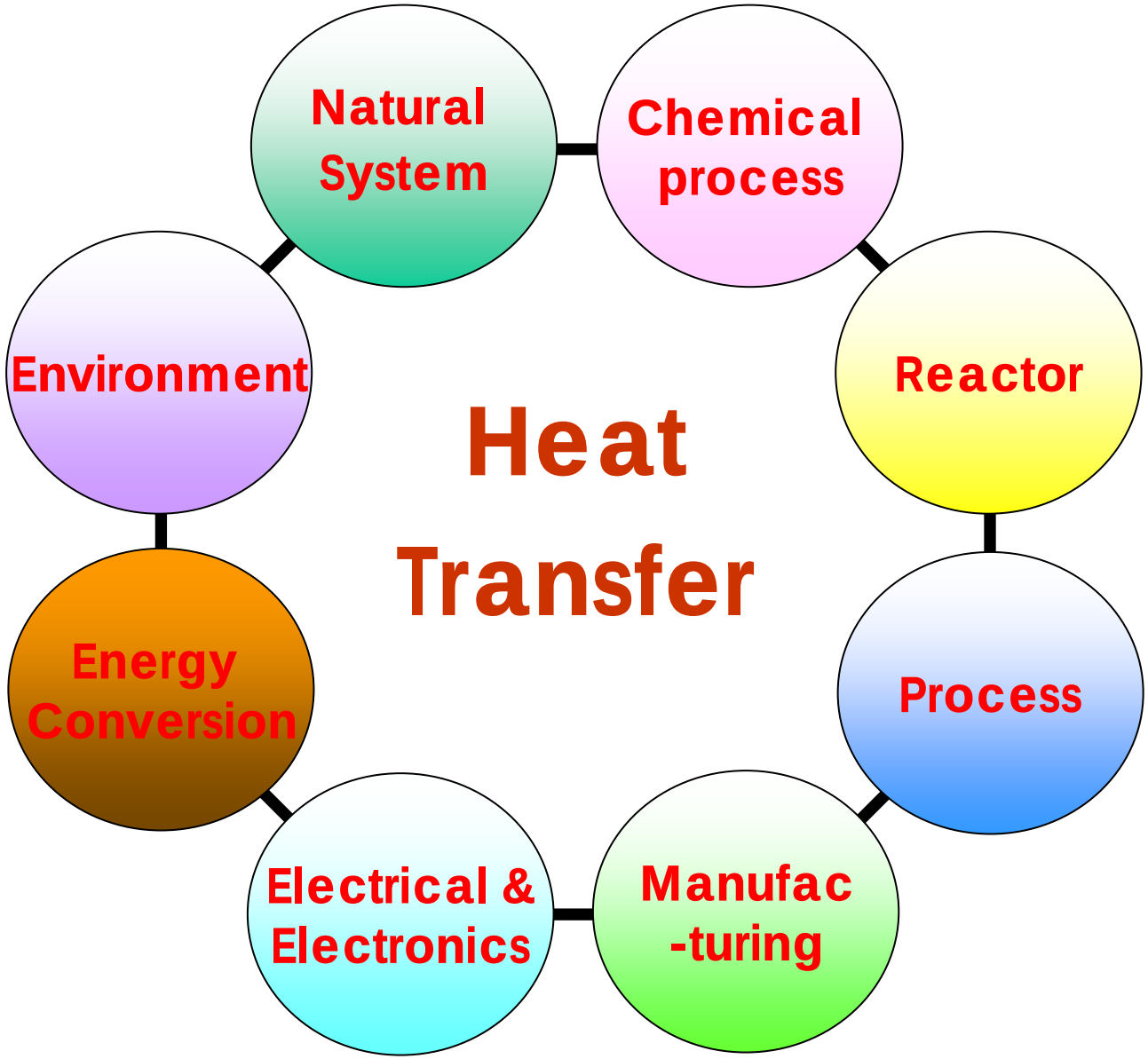
Infrared (IR) Thermometer





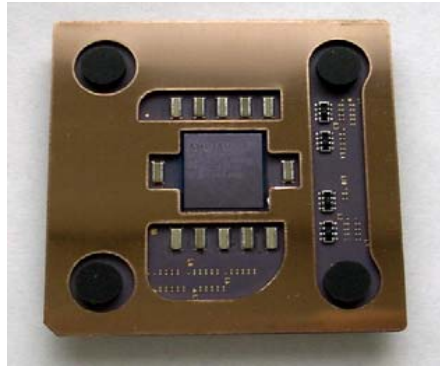


Application of Heat Transfer

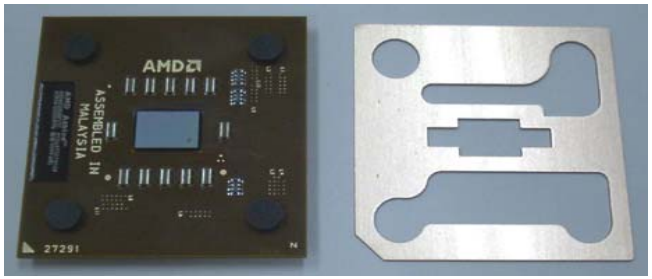


Illustrations：Conduction

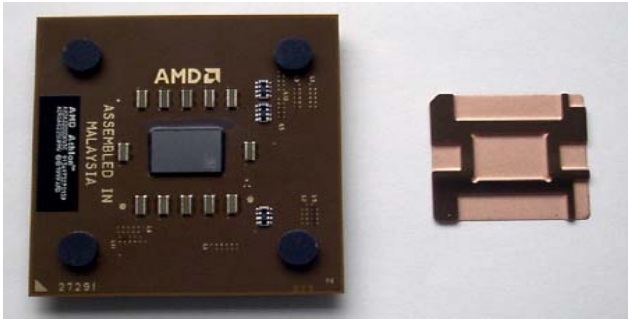
CCD素子だけが熱伝導シートで軽く張り付いているだけ



CPU用熱伝導板



Athron XPThoroughbred2200CPUID 680 CPU用熱伝導板

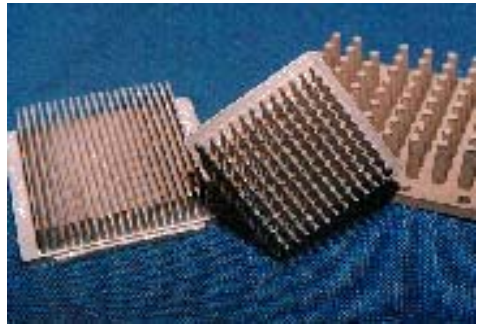


CPUは付属しいません CPU用熱伝導板

CPU周りに銅の熱伝導板を
置くのもいいでしょうでも

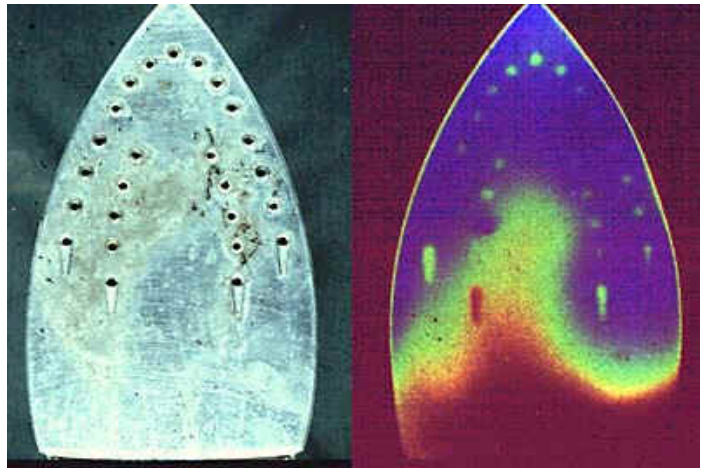
Illustrations : Conduction

CPUは付属しいません CPU用熱伝導板

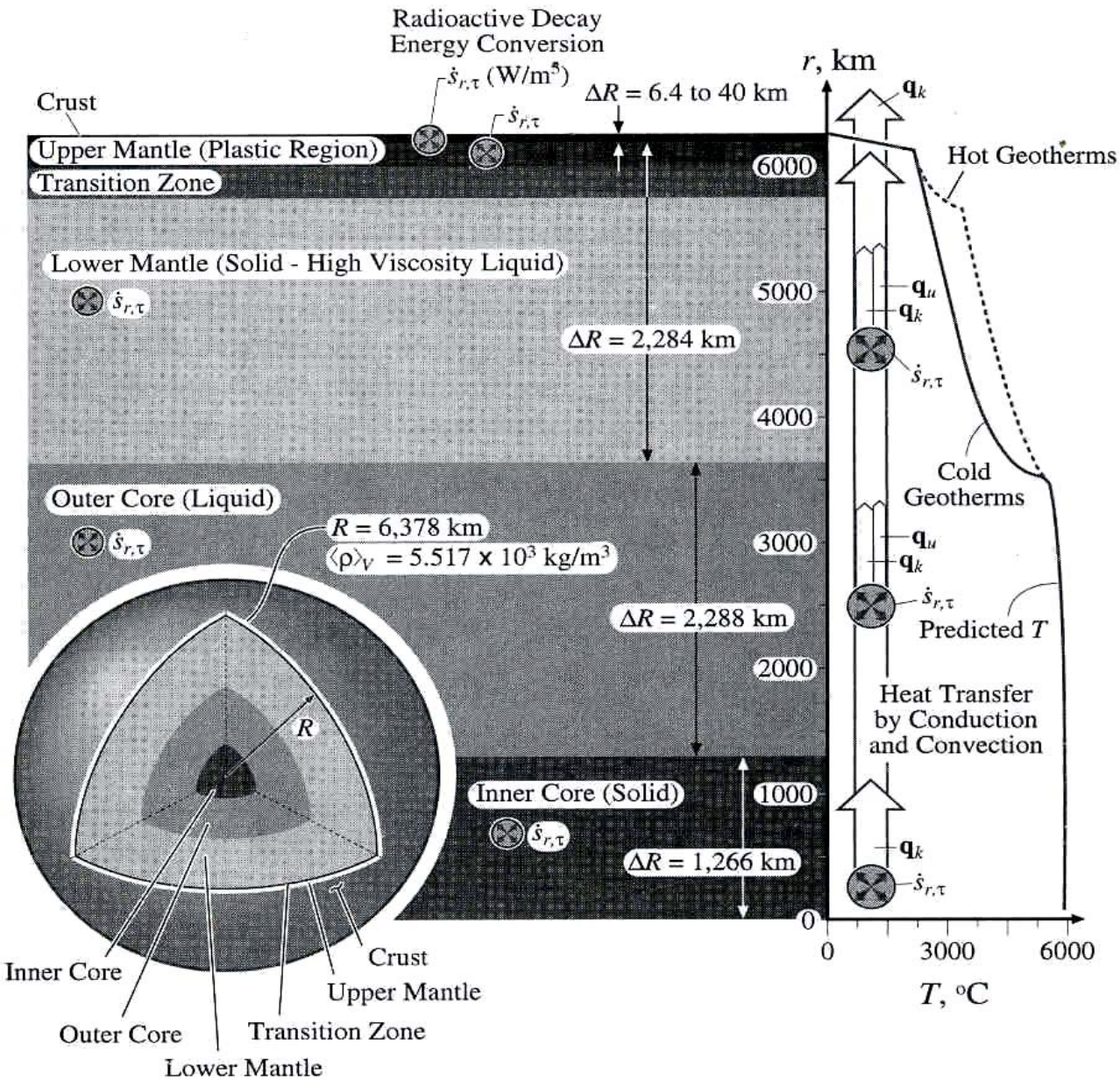


GSI Creos 電子部品用高熱伝導材料 AlSiCシリコン含有アル ...

円柱熱伝導体と多段フィンを採用したCPUクーラーが登場



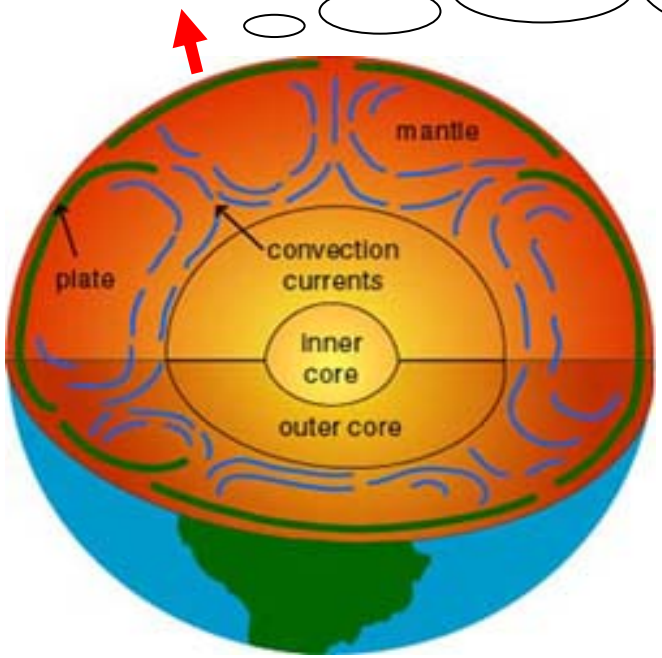
Inner Earth

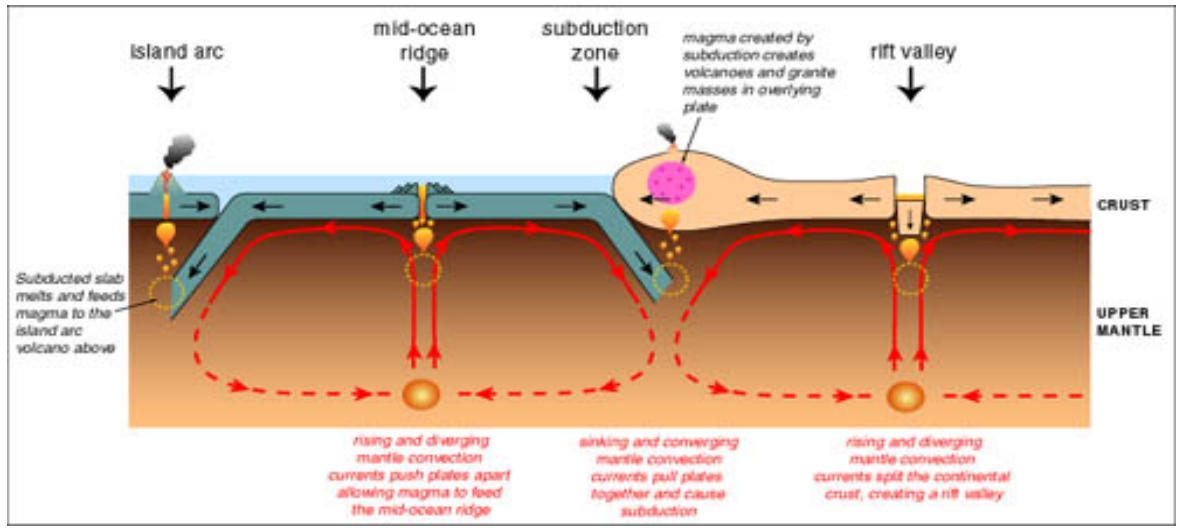

Radioactive Decay
Energy Conversion
$\dot{s}_{r,\tau}$ (W/m³)
ΔR = 6.4 to 40 km
r, km
Crust
Upper Mantle (Plastic Region)
Transition Zone
Lower Mantle (Solid - High Viscosity Liquid)
ΔR = 2,284 km
Outer Core (Liquid)
R = 6,378 km
$\langle\rho\rangle_V$ = 5.517 x 10³ kg/m³
ΔR = 2,288 km
Inner Core (Solid)
ΔR = 1,266 km
6000
5000
4000
3000
2000
1000
0
$\mathbf{q}_k$
$\mathbf{q}_u$
Hot Geotherms
Cold Geotherms
Predicted T
Heat Transfer by Conduction and Convection
0
3000
6000
T, °C
Inner Core
Outer Core
Lower Mantle
Transition Zone
Upper Mantle
Crust

Illustrations : Convection

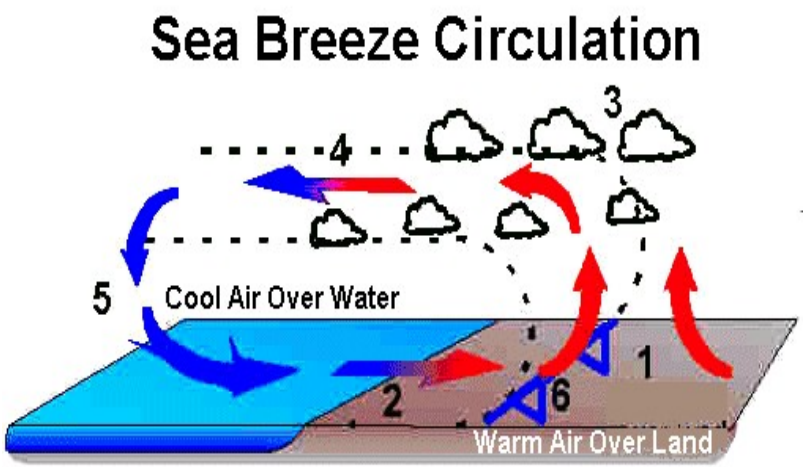
Heat Conduction Rate
=0.01 Btu/(h)(ft^2)

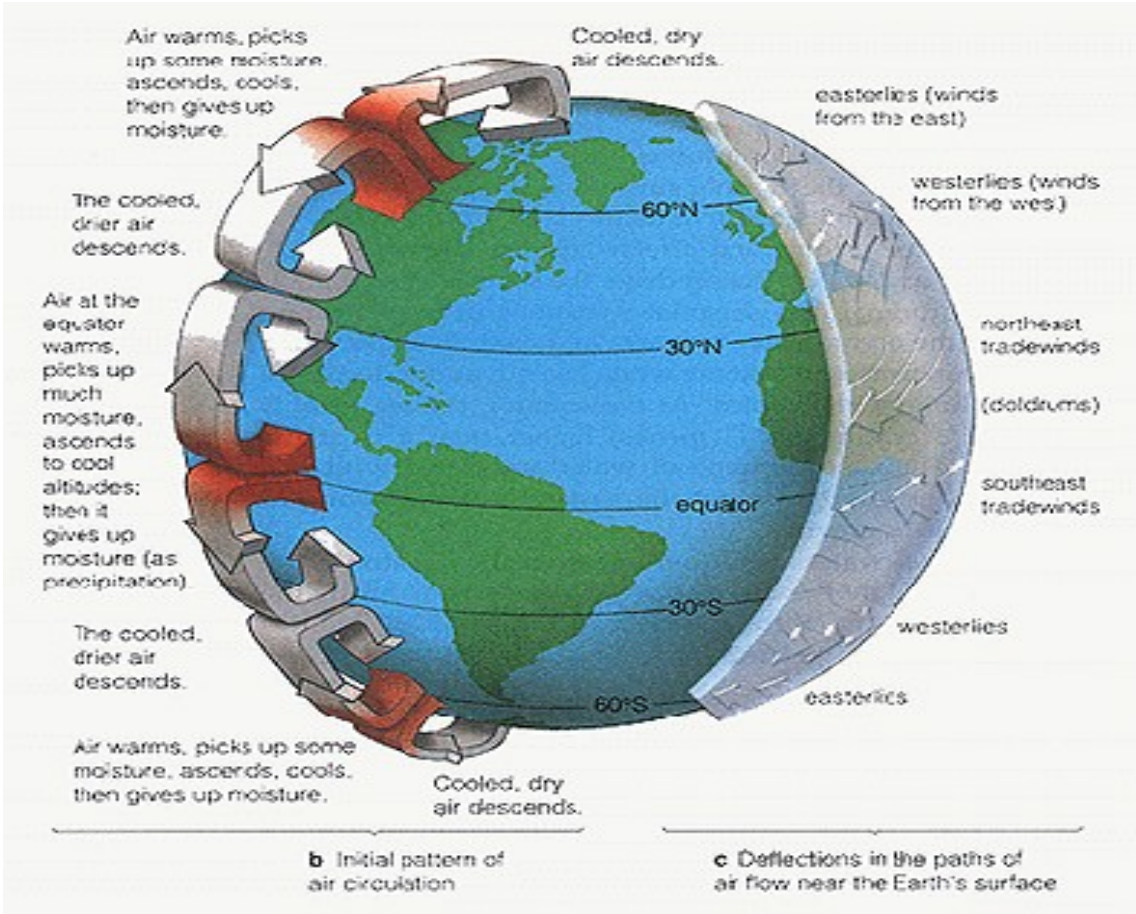
This heat transfer has little effect on surface condition because conduction rate is far less than the rate at which heat is transferred to and from the surface by other mechanisms.





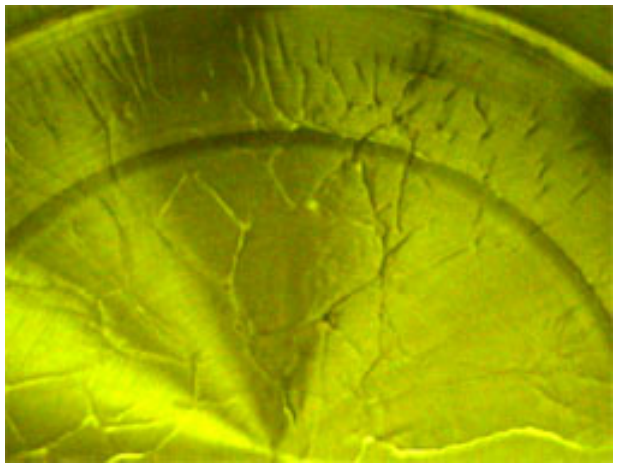
Illustrations : Convection



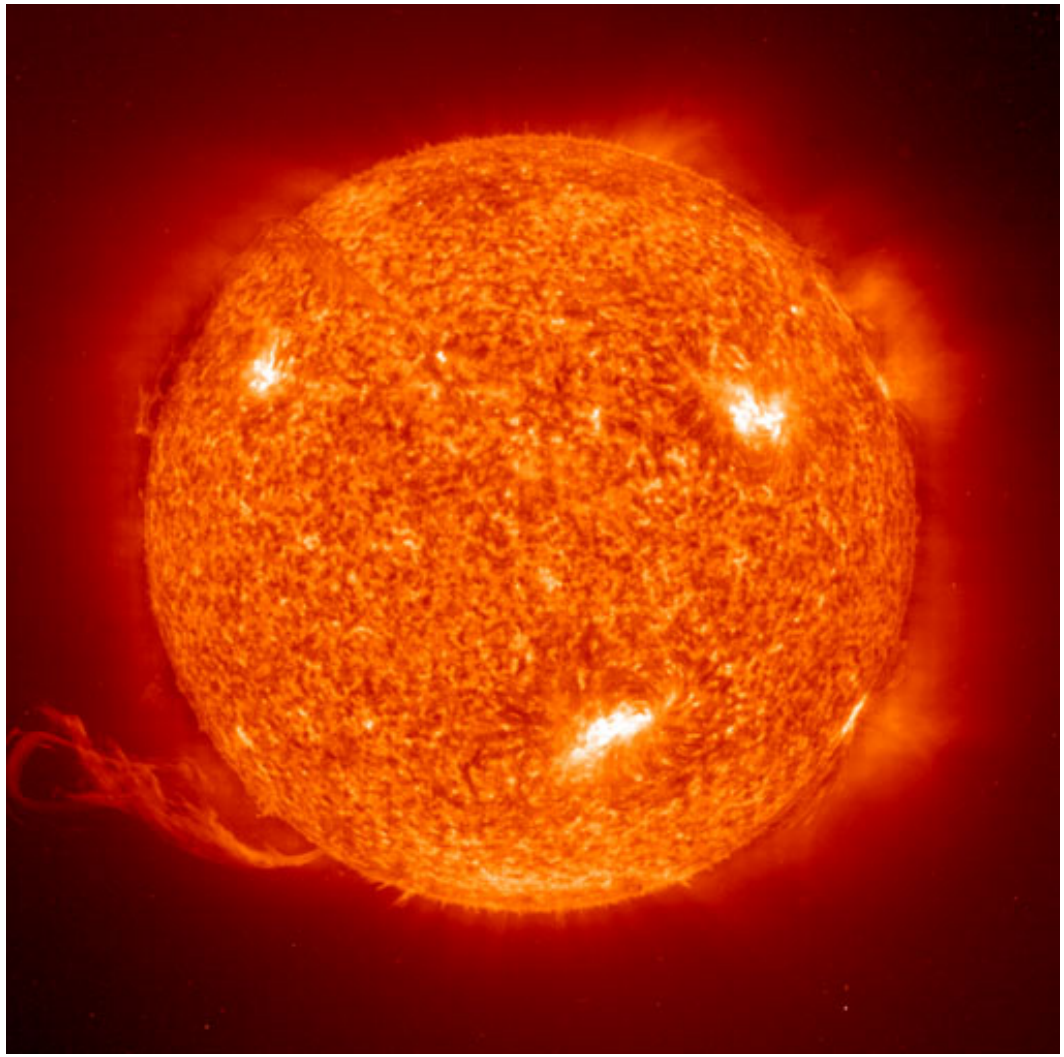


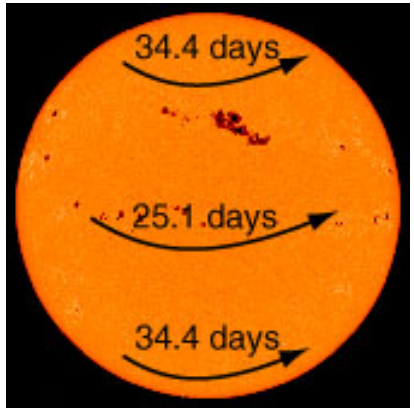
Illustrations : Convection

Convection cells are visible in the heated cooking oil in the pot at left. Heating the oil produces changes in the index of refraction of the oil, making the cell boundaries visible. Circulation patterns form, and presumably the wall-like structures visible are the boundaries between the circulation patterns.



Illustrations : Convection





$m=2x10^{30}kg$

Earth =1

Sun=333,000

$D=1400x10^{6}m$

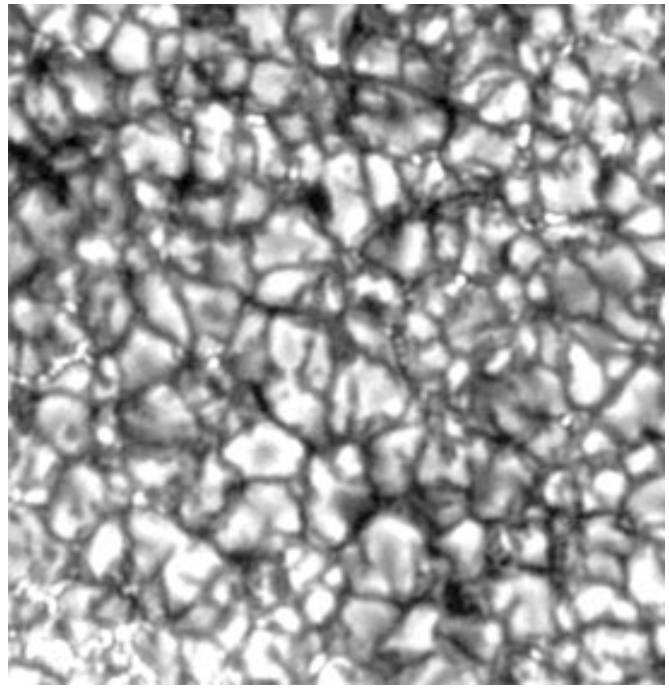
Density=1.41

$g=274g_0$

Being a gaseous body, the Sun does not have a single period of rotation like a rigid body. The sunspots provide a convenient reference for the measurement of the rotation period at different latitudes. The period of rotation averages 25.4 days, varying from 34.4 days at the poles to 25.1 days at the equator (Chaisson). Its axis is tilted 7.25° relative to the ecliptic.

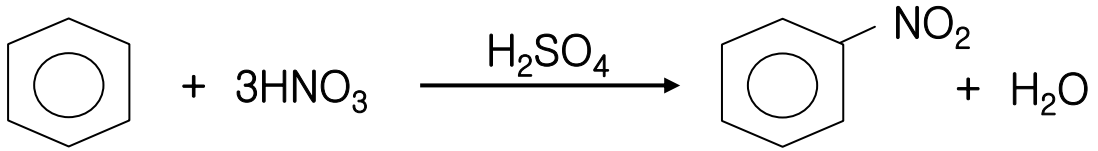
Illustrations : Convection

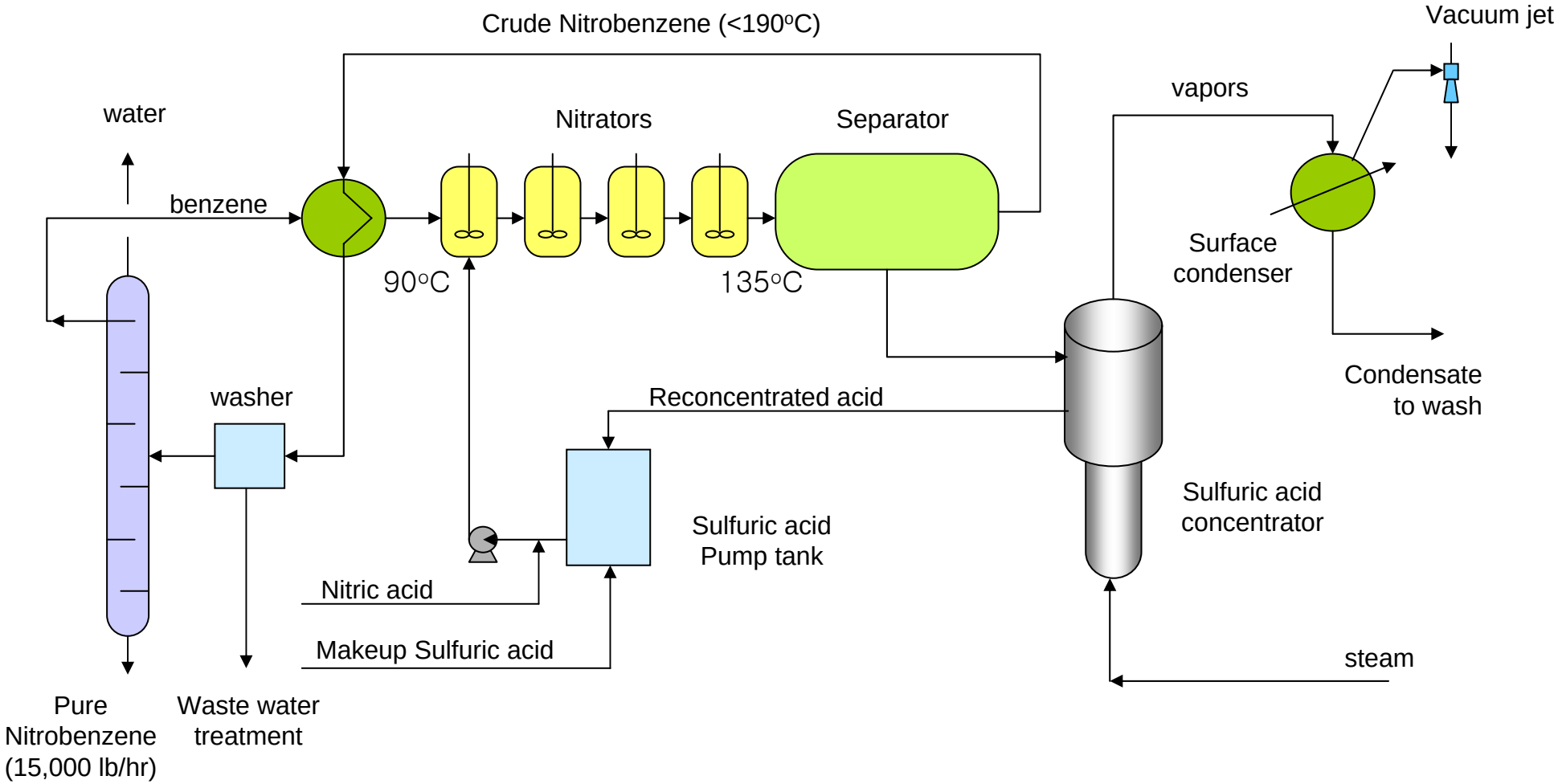
Convection is thought to play a major role in transporting energy from the center of the Sun to the surface, and in movements of the hot magma beneath the surface of the earth. The visible surface of the Sun (the photosphere) has a granular appearance with a typical dimension of a granule being 1000 kilometers. The image at right is from the NASA Solar Physics website and is credited to G. Scharmer and the Swedish Vacuum Solar Telescope. The granules are described as convection cells which transport heat from the interior of the Sun to the surface.



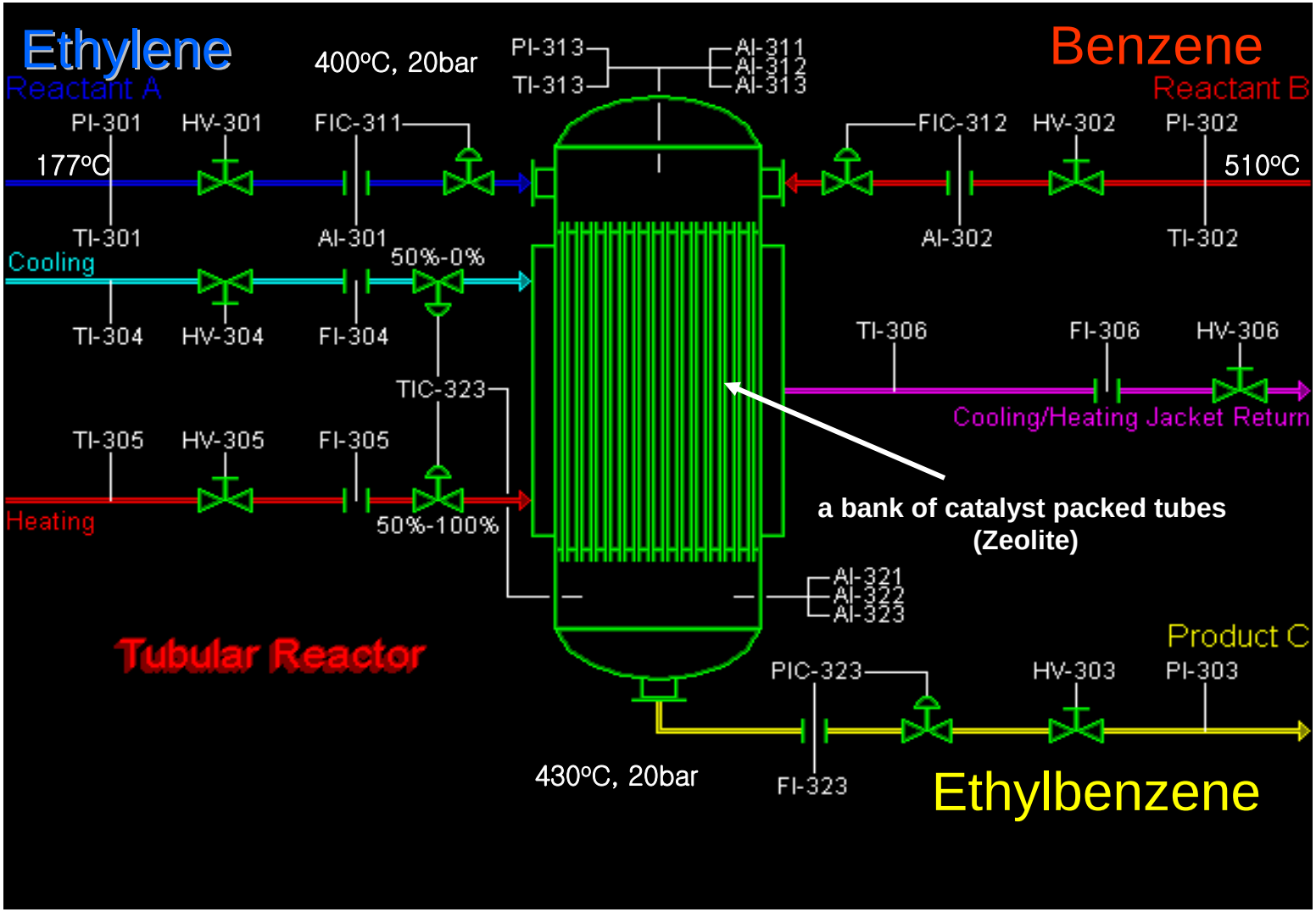
http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heatra.html#c3

Flow sheet for the production of nitrobenzene



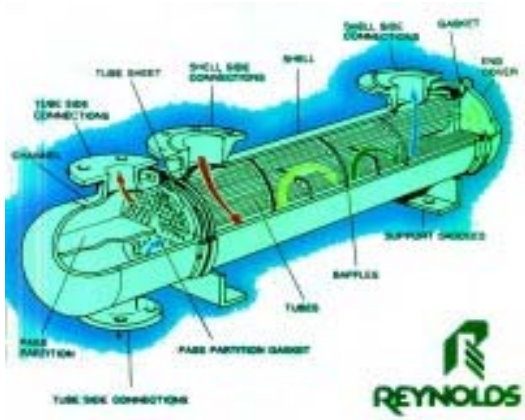


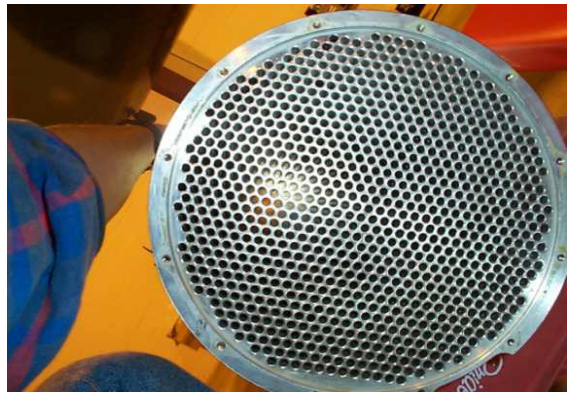
Tubular Reactor for production of ethylbenzene

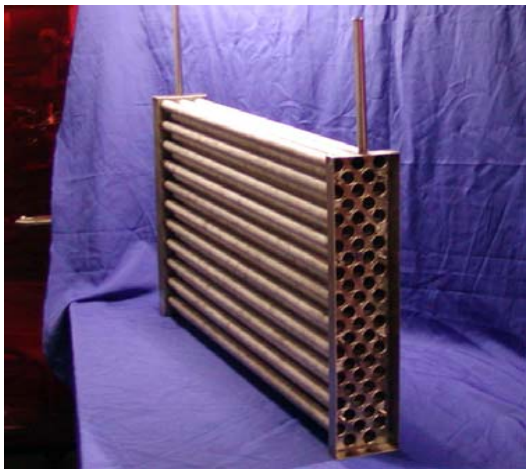


The default configuration catalytically reacts ethylene (reactant A) with benzene (reactant B), an exothermic reaction, to produce ethylbenzene (product C), an intermediate chemical used in the manufacture of styrene monomer. *(http://www.simtronics.com/catalog/spm/spm2200a.htm)*

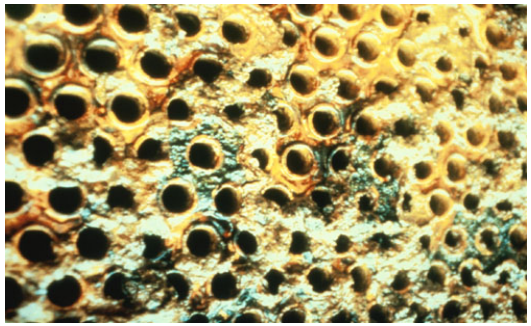
Illustrations : Heat Exchanger

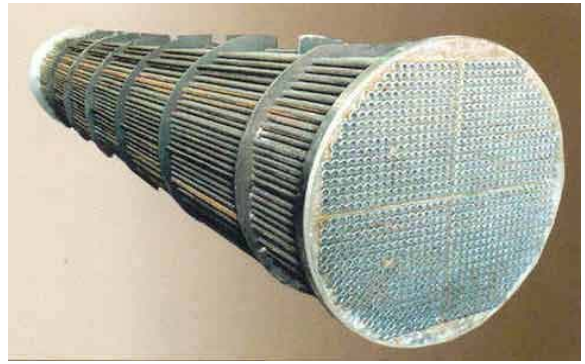




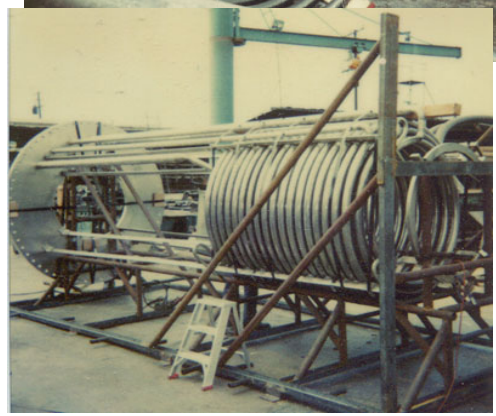


Illustrations : Heat Exchanger





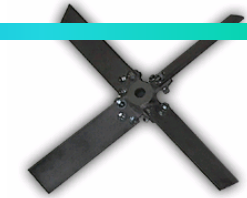
A Heat Exchanger Fouled by a Biofilm



Cutaway View of CSTR

http://www.jeiopi.co.kr/english/prd/impeller.htm

pitched blade turbine



Spiral Agitator

Turbine Type Impeller

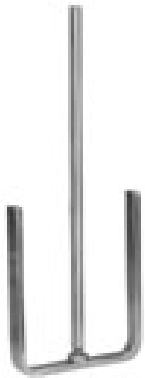
flat blade radial turbine

Gas Entrainment Impeller

Helix Impeller

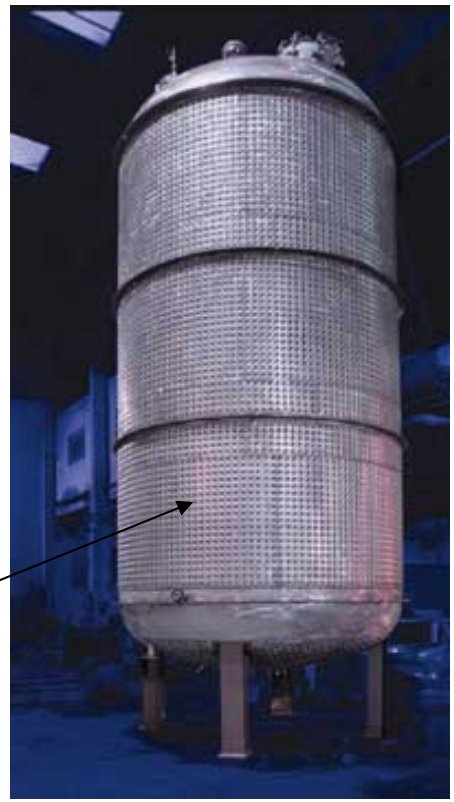
Marine Type Propeller

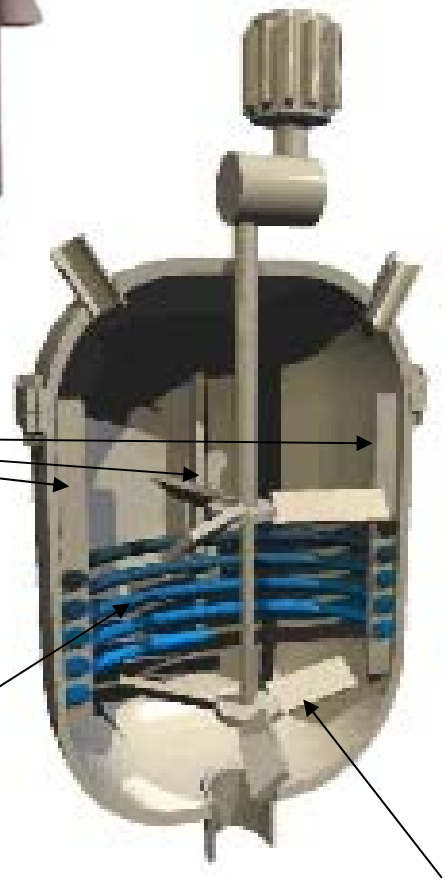
Anchor Stirrer



Hydrofoil

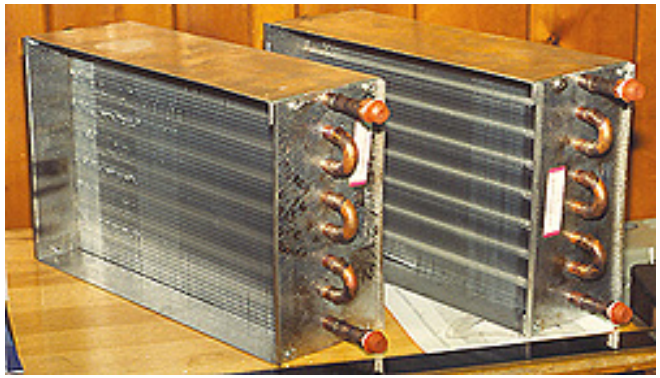
Type of Jacket

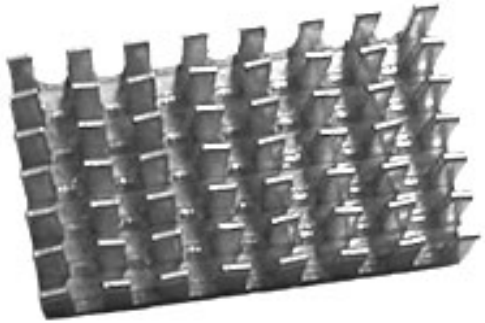




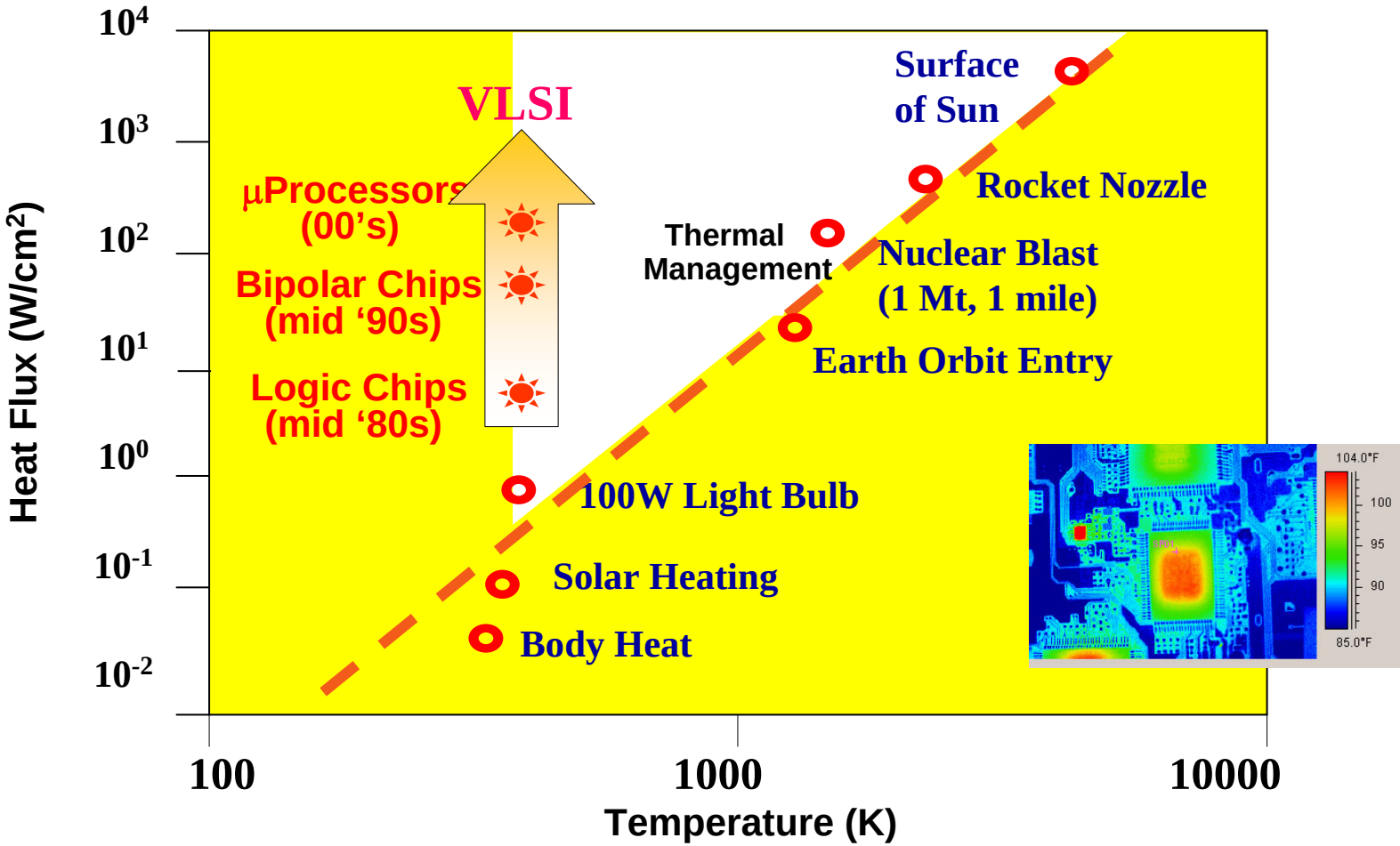
www.centralfabricators.com/hpipej.htm

Heat Transfer Enhancer: Fin





Electrical & Electronics



- local heat flux of 200-300 W/cm^2, today
- equivalent to that of 1 Mt nuclear blast at 1 mile from ground zero
- only one order of magnitude less than the sun

Heat Transfer Enhancer: Fan & Fin

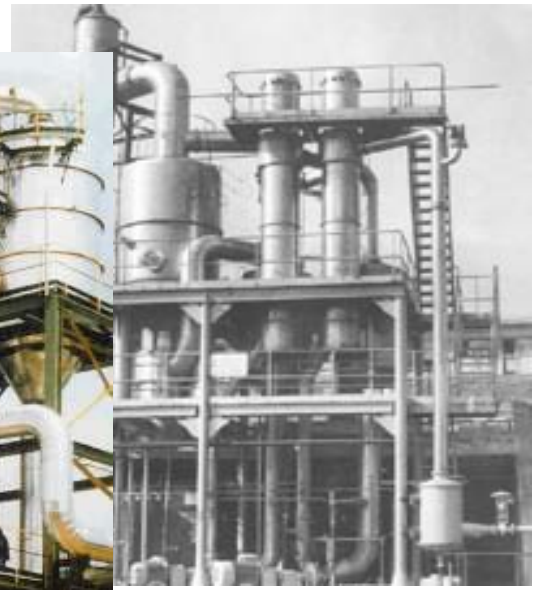
Evaporator



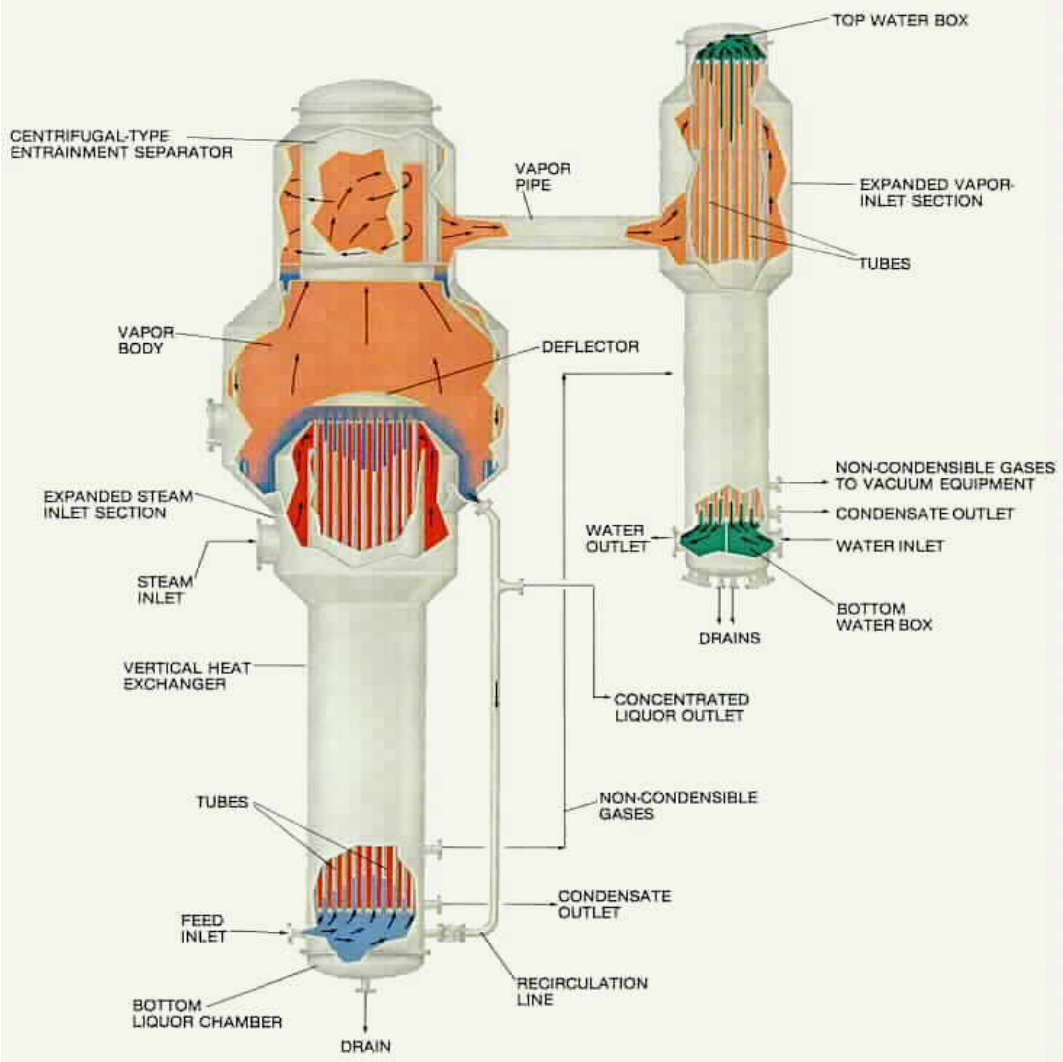




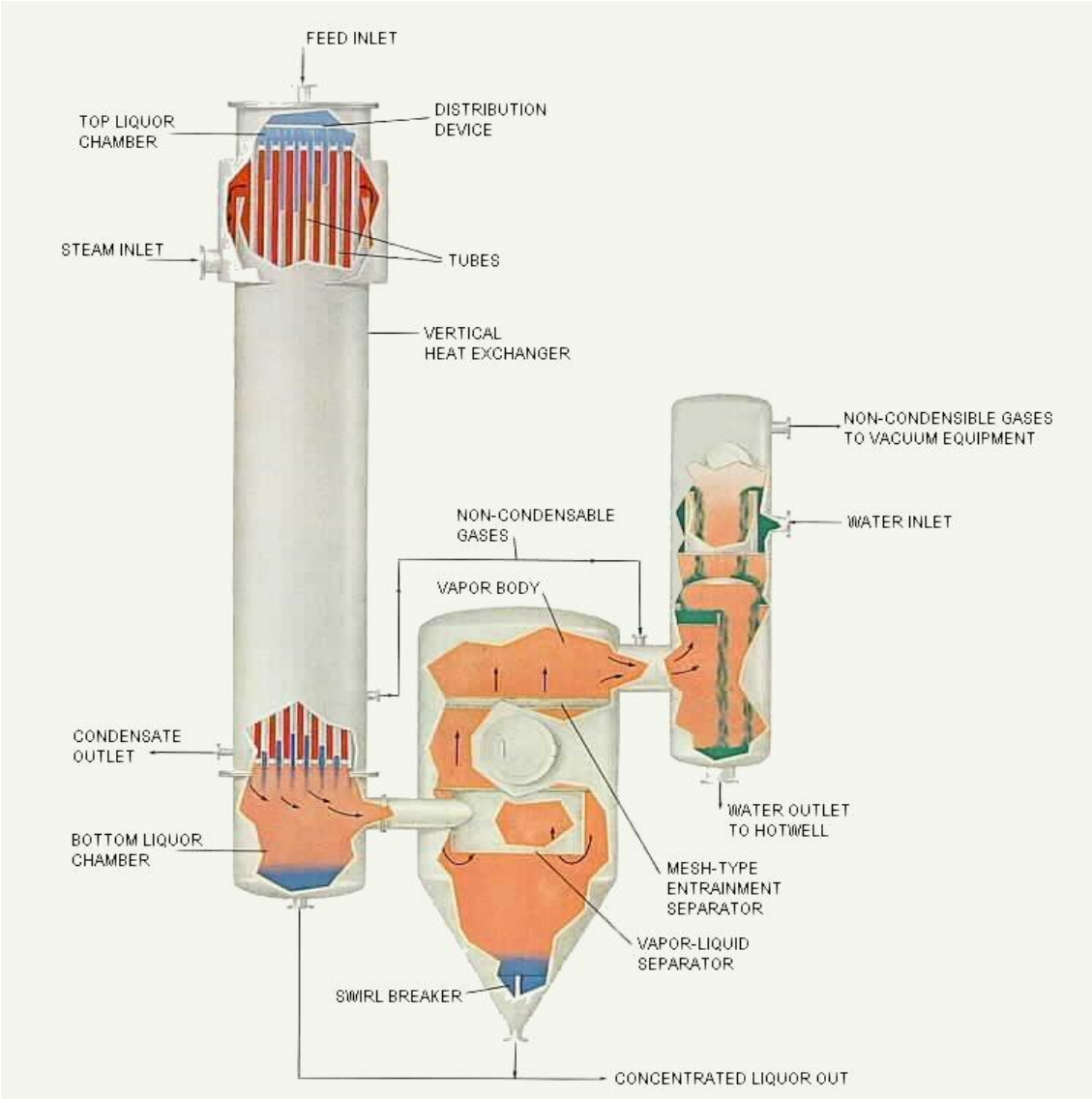


Evaporator

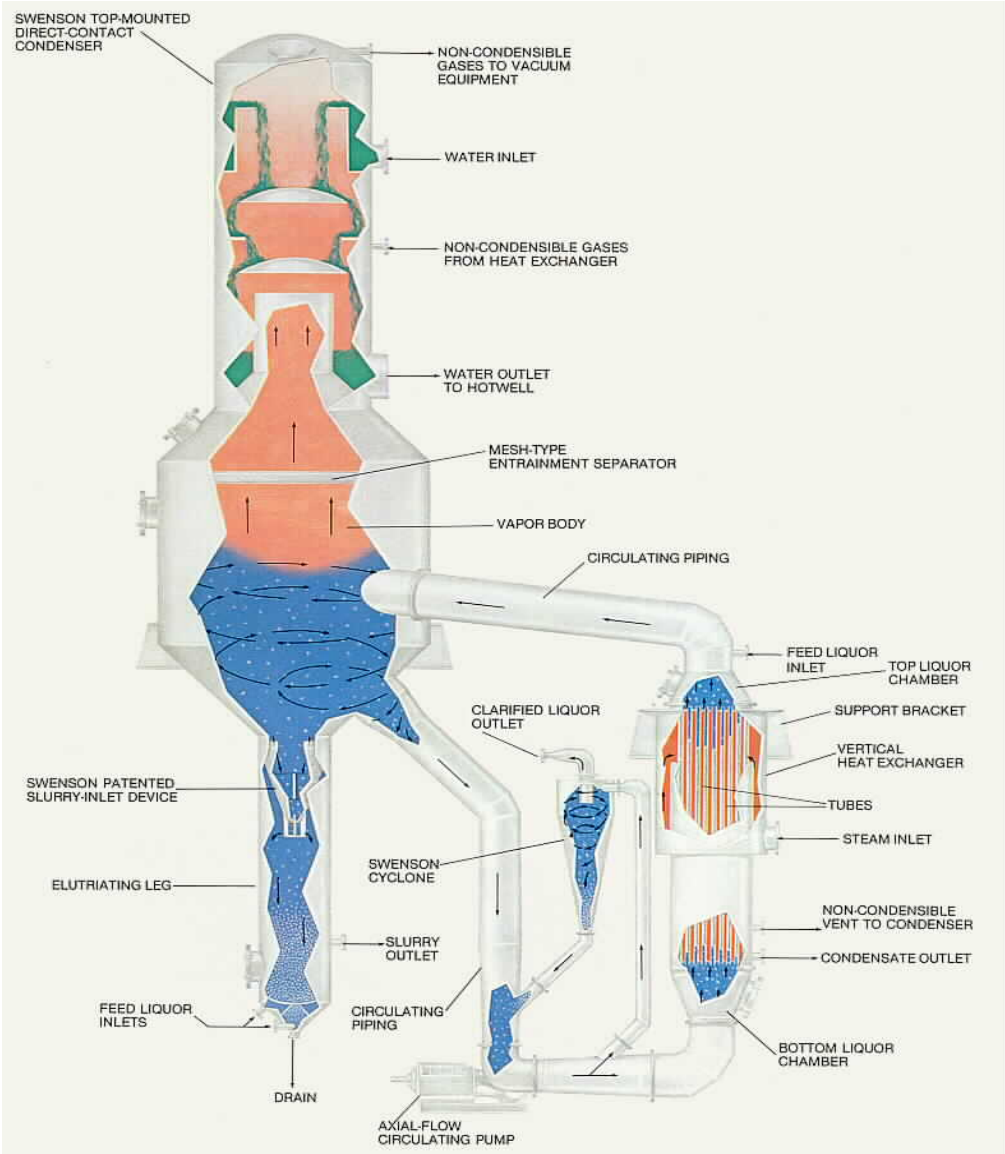

TOP WATER BOX
CENTRIFUGAL-TYPE ENTRAINMENT SEPARATOR
VAPOR PIPE
EXPANDED VAPOR-INLET SECTION
TUBES
VAPOR BODY
DEFLECTOR
NON-CONDENSIBLE GASES TO VACUUM EQUIPMENT
EXPANDED STEAM INLET SECTION
CONDENSATE OUTLET
WATER OUTLET
WATER INLET
STEAM INLET
BOTTOM WATER BOX
DRAINS
VERTICAL HEAT EXCHANGER
CONCENTRATED LIQUOR OUTLET
TUBES
NON-CONDENSIBLE GASES
CONDENSATE OUTLET
FEED INLET
RECIRCULATION LINE
BOTTOM LIQUOR CHAMBER
DRAIN

Evaporator


FEED INLET
TOP LIQUOR CHAMBER
DISTRIBUTION DEVICE
STEAM INLET
TUBES
VERTICAL HEAT EXCHANGER
NON-CONDENSIBLE GASES TO VACUUM EQUIPMENT
NON-CONDENSABLE GASES
WATER INLET
VAPOR BODY
CONDENSATE OUTLET
WATER OUTLET TO HOTWELL
BOTTOM LIQUOR CHAMBER
MESH-TYPE ENTRAINMENT SEPARATOR
VAPOR-LIQUID SEPARATOR
SWIRL BREAKER
CONCENTRATED LIQUOR OUT

Evaporator

Three-stage, Forced-Circulation Evaporator used to concentrate wet process phosphoric acid



Evaporator

The largest salt evaporator in the world at Montedison, Cirò Marina, Italy. This is a multiple-effect forced-circulation evaporator with a 40 foot recompression body.

Illustrations : 断熱材

최고사용온도: 700℃
열전도도: 0.0298 kcal /m·hr°C

Illustrations : LNG tanker (断熱材)

액화천연가스 운반선. 천연으로 생산되는 비석유계 천연가스(메탄계 탄화수소가 주성분이지만, 실제로는 메탄이 90% 이상을 차지)를 액화한 것을 운반하기 때문에 LMG(액화메탄가스)선이기도 하다. 메탄은 끓는점이 －162 ℃이기 때문에 냉각하여 액화한 메탄을 운반하는 배에서는, 액화가스를 선내에 설비된 탱크 안에 저장하는데 초(超)저온의 유지가 어렵다

All LNG tankers have double hulls and double-walled, insulated cargo storage tanks to guard against leaks and keep the LNG cold (think of them as giant reinforced thermos bottles).

Illustrations : LNG tanker (断熱材）

Moss spherical tanker

NASA Silica Aerogel

NASA's Jet Propulsion Laboratory has been listed in the Guinness World Records for creating the world's lightest solid. Aerogel is also extremely expensive, costing approx. $200-$300 a cubic inch.

Some Aerogel Facts

It is 99.8% Air.

Provides up to 39 times more insulation than the best fiberglass insulation.

It is 1,000 times less dense than glass.

It was used on the Mars Pathfinder Sojourner rover.

Will be used to insulate the batteries of the 2003 Mars Exploration Rovers.

Aerogel will catch a piece of a comet on the Stardust mission in 2003/2004.

This is a piece of Silica Aerogel, the same type that is used in the Mars Pathfinder Rover.

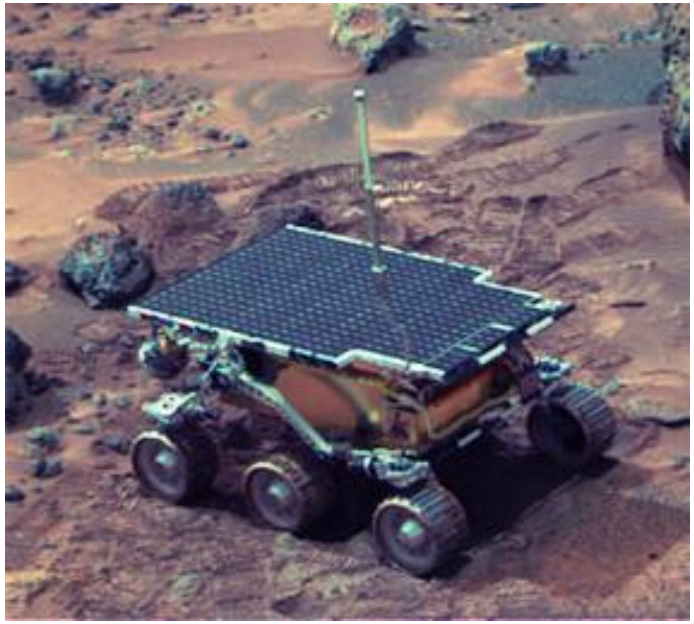
Aerogel Insulator

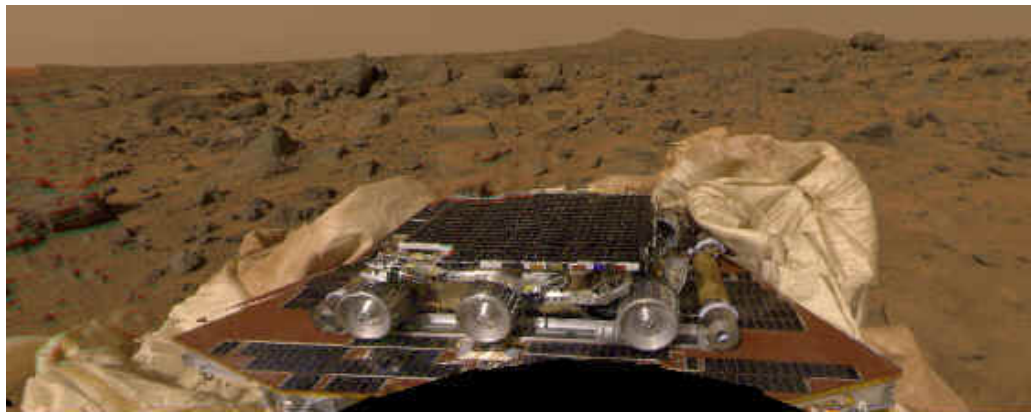
Corpo Nove incorporated the Spaceloft™ version of the NASA-developed aerogel material into this jacket, which was tested during an Antarctic expedition.

Using aerogel in jackets such as this one will provide wearers with unsurpassed insulation.

One inch of aerogel, a new ultra-lightweight material, insulates just as well as ten inches of fiberglass or a window with 10 double panes of glass

NASA Silica Aerogel : Pathfinder





Ceramic Insulator

Process / Thermal Conductivity of Nanofluids