BASICS OF INFRARED

NIPPON AVIONICS CO.,LTD.

Content

1. Things often misunderstood regarding infrared thermography

①Isn’t the infrared camera emitting something?

No, nothing is emitted.
It merely detects infrared radiated from an object passively.
It should be noted, however, that it may be affected by reflections in the periphery.

②Isn’t the wavelength used to measure the temperature distribution?

No, the temperature distribution is measured by the amount of infrared energy, not the wavelength.

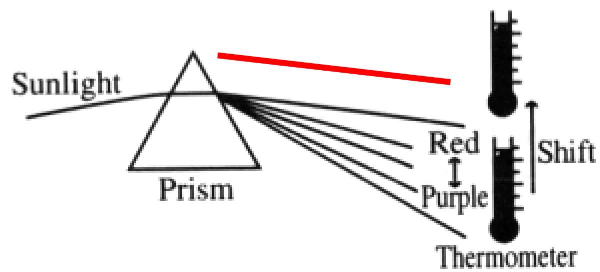
③Can’t we see the rear side temperature of an object from its front side?

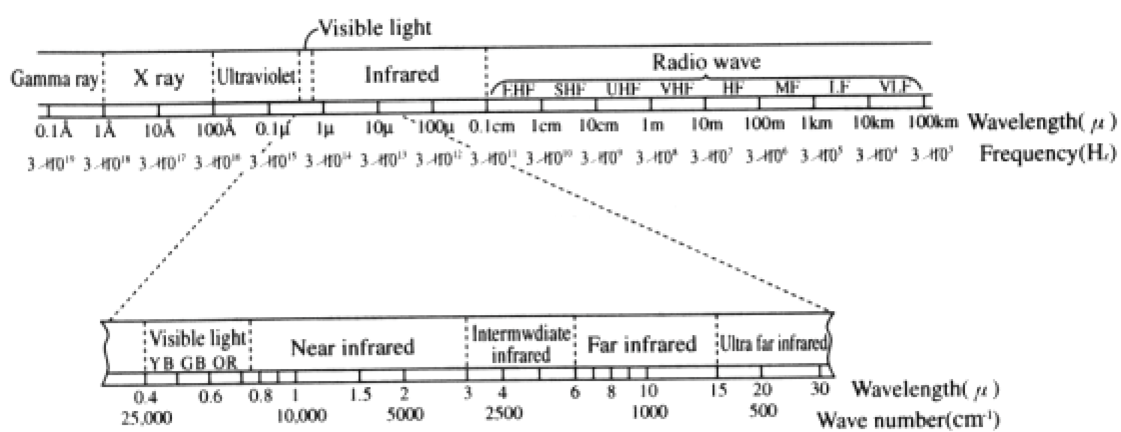
No, we cannot see the rear side from the front as we detect the infrared emitting from the front face of an object.
On the other hand, <u>we can estimate the rear side temperature if a temperature distribution is created on the front side due to the difference of heat conductivity</u>.

2.What is infrared

■Discovery of infrared

Infrared was discovered in 1800 by a British astronomer named Herschel. While conducting spectrum analysis of sunlight using a prism, Herschel accidentally noticed that there was an invisible light outside of the red light which raises the temperature of an object.

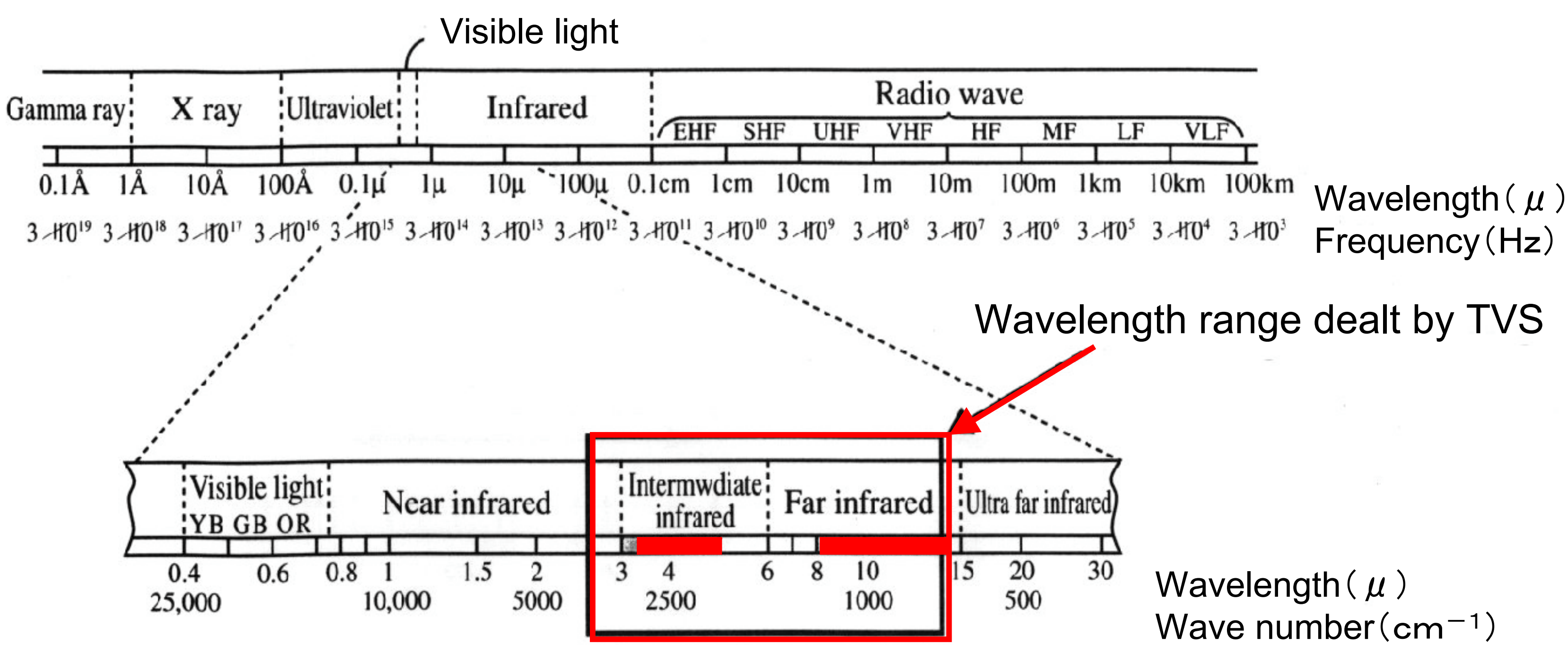




2.What is infrared

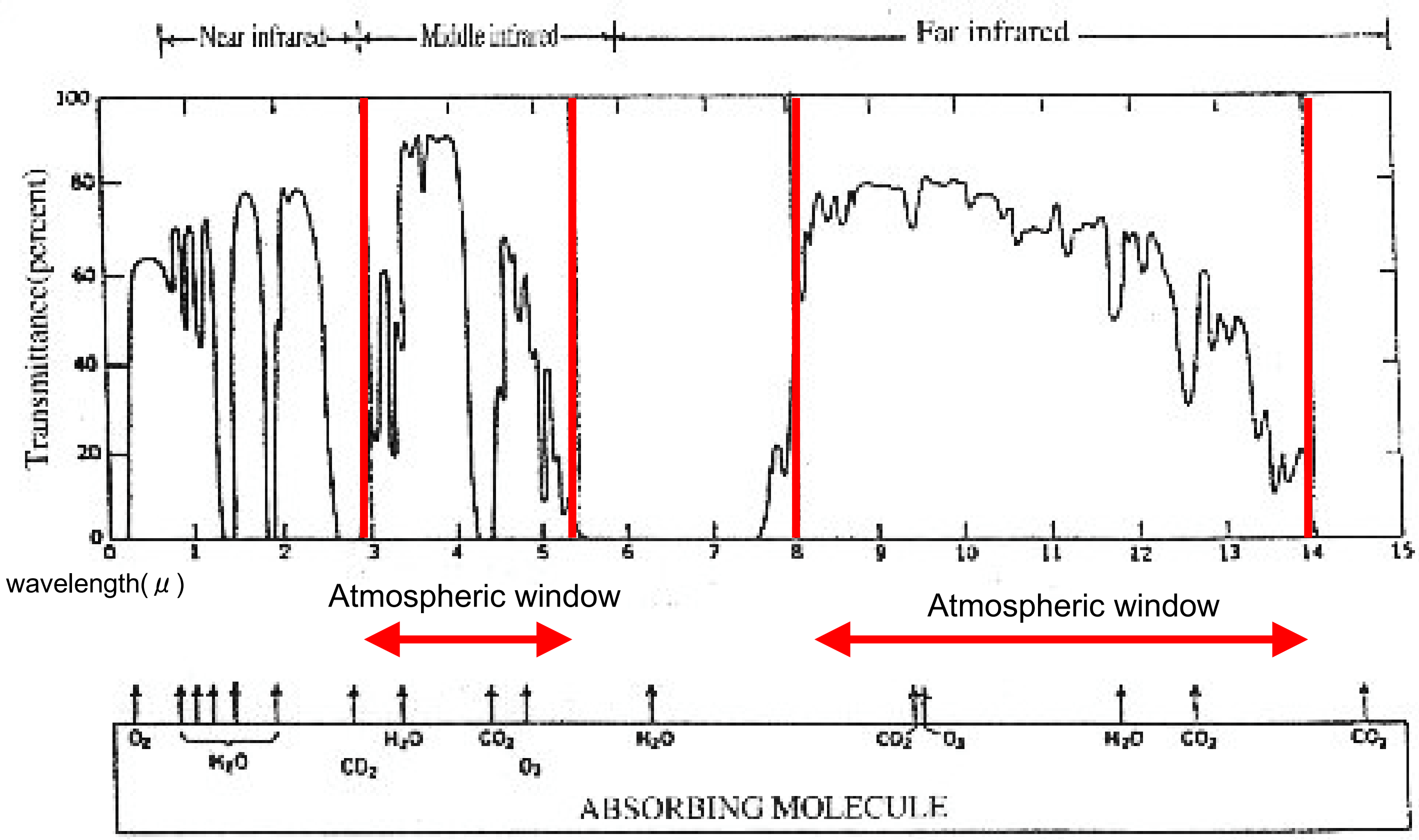
It is an electromagnetic wave

Wavelength is 0.7 μ m or longer
Wavelength is 1mm or less = Frequency is 300GHz or more.



2.What is infrared

Transmission characteristics of infrared in the atmosphere



Elevation 0m, Horizontal path 1.8km, Condensation length of moisture 17mm

2.What is infrared

Characteristics of infrared

(1) It is not visible as its wavelength is longer than the visible light.

It is independent from the brightness or darkness of the visible light.

(2) It is radiated naturally from all objects having the temperature of absolute 0° K or higher.

Therefore, it is applicable to all kinds of field.

(3) It has a characteristic of heating an object.

Therefore, it is sometimes called the "heat ray".

(4) It is a kind of light (electromagnetic wave).

It can travel through vacuum.

(5) Infrared energy and temperature of an object are co-related.

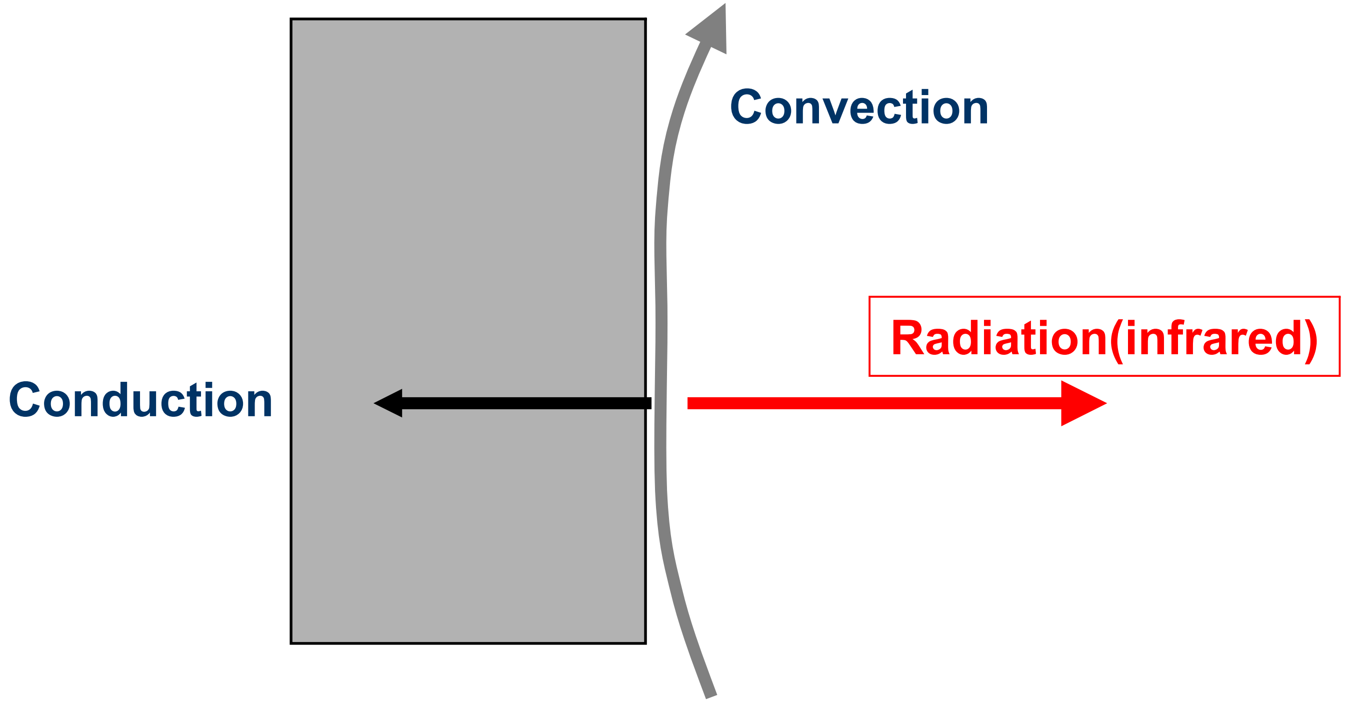
Therefore, the temperature of an object can be measured.

3. How the heat transfers

Radiation: It is a type of heat conduction whereby the heat is conducted directly from the surface of an object as an infrared energy.

Convection: The heat is conducted by the heated portion of a gas or a liquid moving upward.

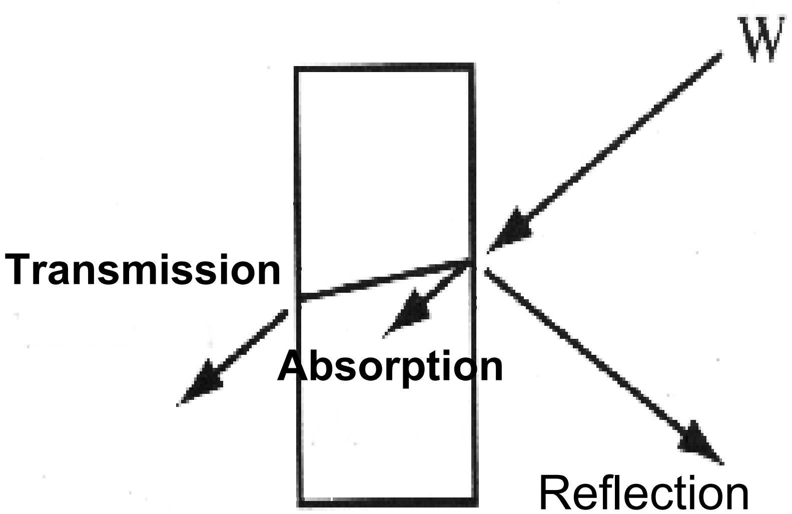
Conduction: It is a type of heat conduction mainly through a solid object.



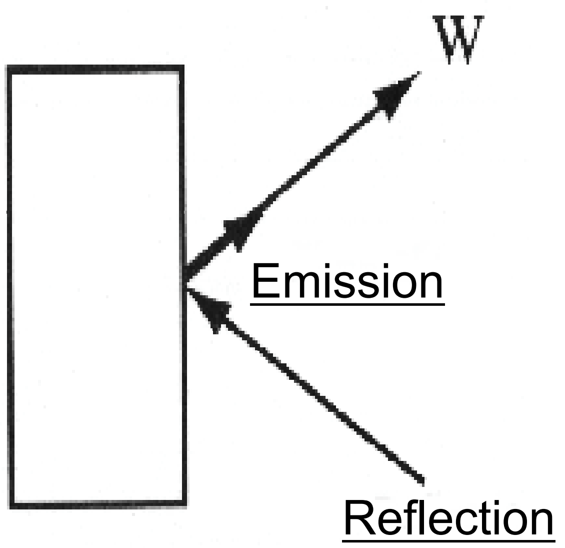
4. Emission, reflection and transmission of infrared

An object which absorbs infrared well emits infrared well.

W=Transmission + Reflection + Absorption

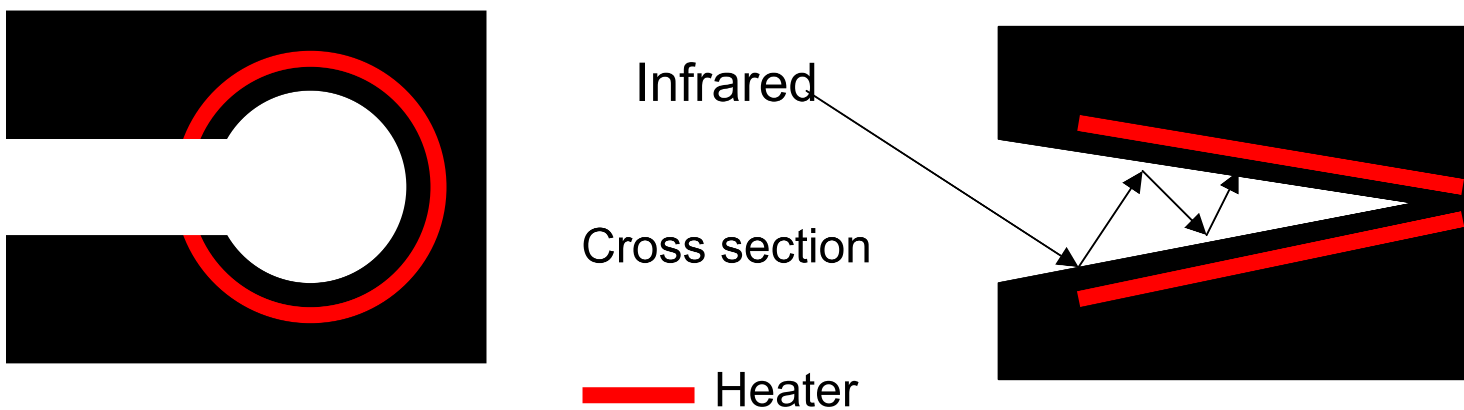


If transmission=0,
W = Emission + Reflection



5.Blackbody

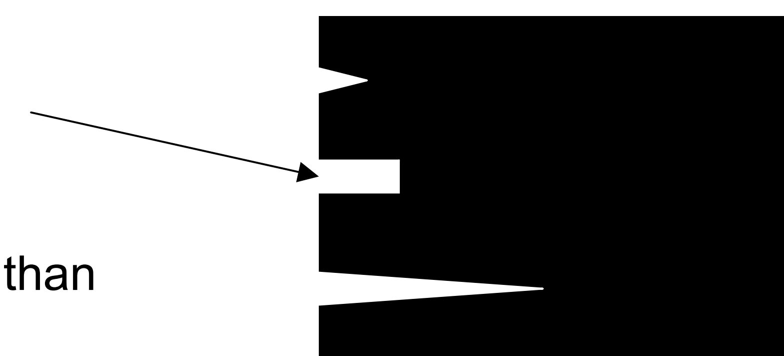
- Emissivity ε = 1.0
- 100% radiation = 100% absorption
- It is structured in a way that the incident infrared will not come out.
- Temperature calibration is made using such a heat source.
- If the emissivity is different, measured temperature value will be different.
- There is a case that a crack is created resulting in natural creation of a blackbody like thing, and the temperature is measured to be higher than the periphery.



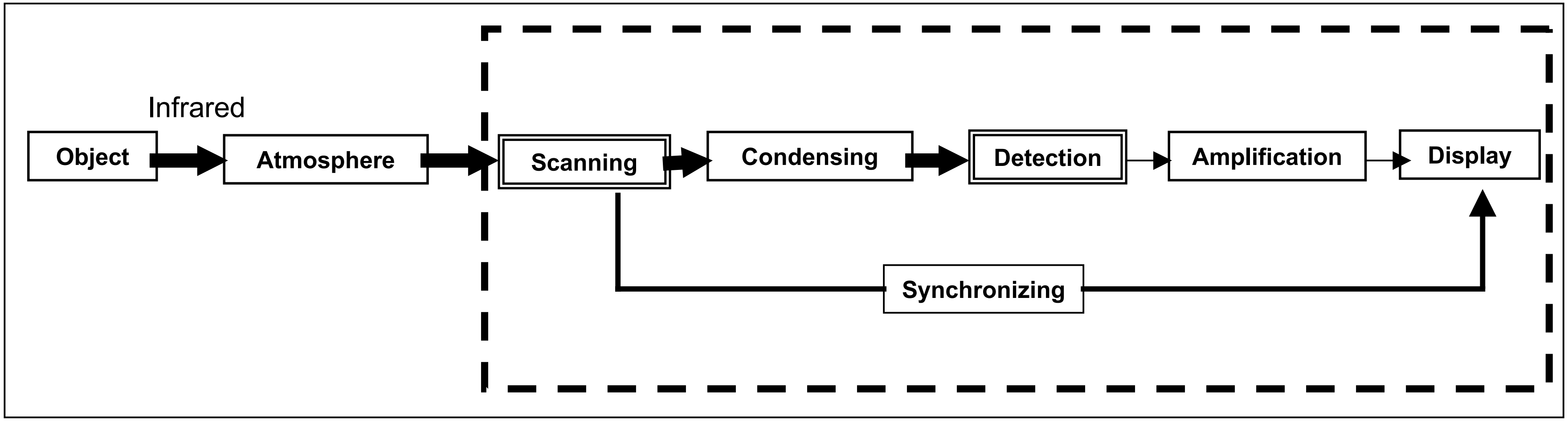
Apparent emissivity is improved due to a cavity.

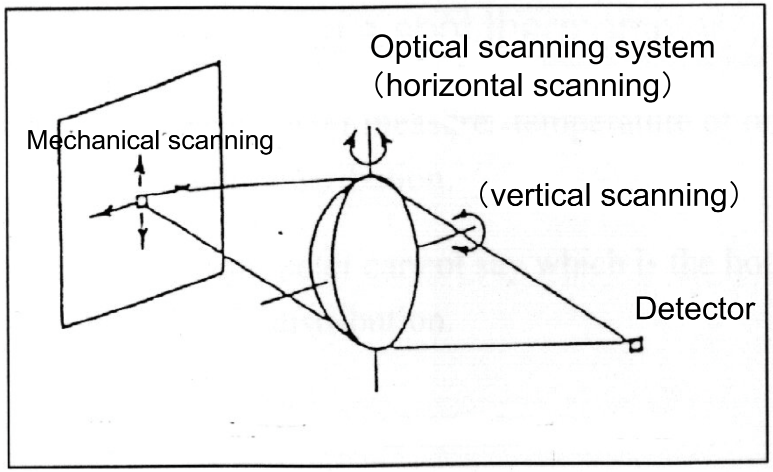
↓

Temperature appears to be higher than the periphery: Cavity radiation

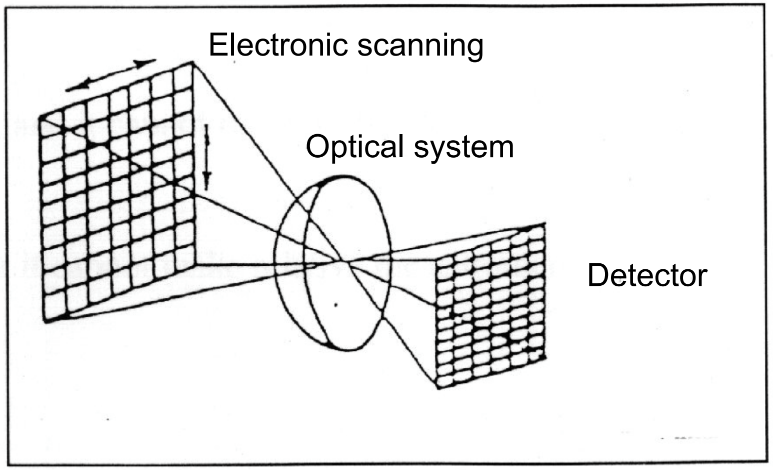


6.Principle of measurement by infrared thermography equipment





(1)Single element detector and scanning mechanism



(2)2 dimensional element detector and scanning mechanism

6.Principle of measurement by infrared thermography

Avio

■Characteristics of infrared thermography

(1) Temperature is captured as a real temperature distribution, and it can be displayed as a visible information.

(2) Temperature can be measured at a distance from an object without contacting.

(3) The temperature can be measured in realtime.

■The difference from a spot thermometer

(1) A spot thermometer measures the temperature of a single point, and it cannot measure as a temperature distribution.

(2) A spot thermometer cannot provide relative measuring such as the measurement of a hot spot or the measurement of a temperature distribution.

6.Principle of measurement by infrared thermography equipment

■The advantages of infrared thermography.

(1) A distribution of surface temperature over a wide area can be compared relatively.

(2) Temperature measurement of a moving object or even an object dangerous to get close to it can be taken easily.

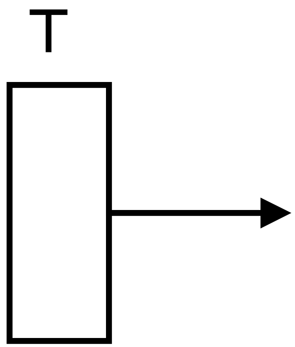
(3) Temperature measurement of a microscopic object can be taken without affecting its temperature.

(4) Temperature measurement of food, medicine or chemicals can be taken without having sanitary issues.

(5) Temperature measurement of an object of which the temperature changes drastically or a phenomenon during a short period of time can be taken.

7.Measurement of temperature distribution

There is a correlation between emitted energy of infrared and surface temperature of an object.



Infrared energy（W）

$W = \sigma T^4$ ： Stefan-Boltzmann's law

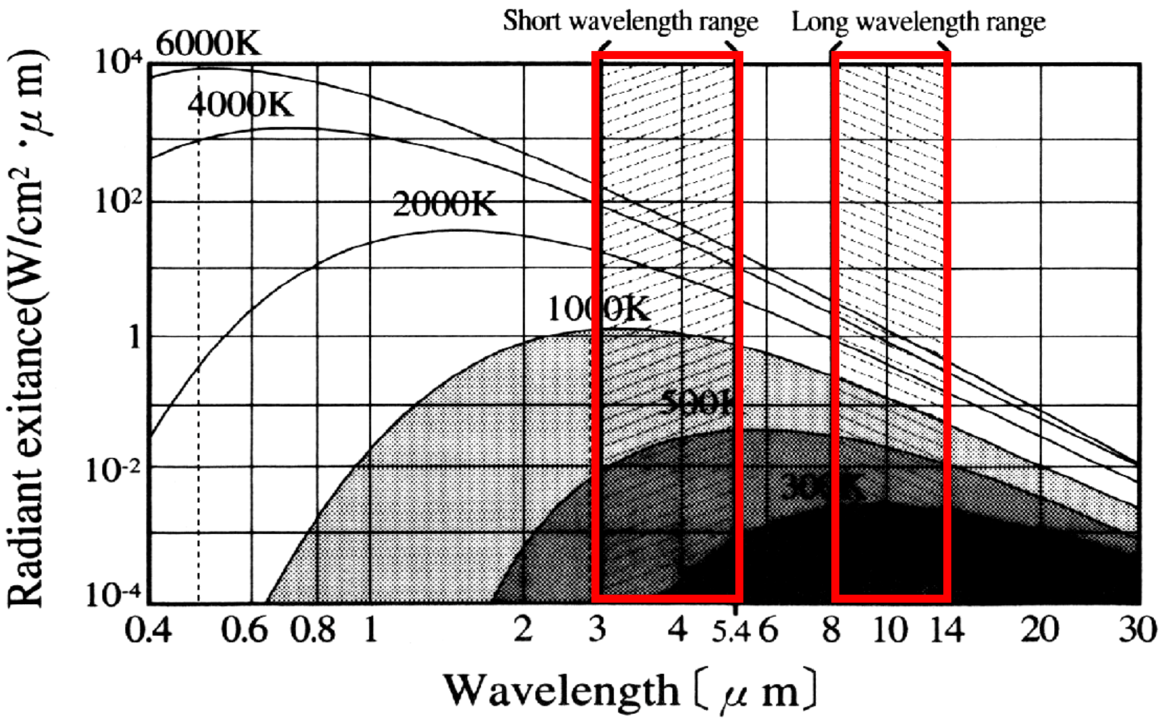
〈Heat and temperature〉

Heat ：A form of energy. Infrared energy is heat energy itself.
Temperature：It is a measure to indicate a status of heat.

7.Measurement of temperature distribution

Relationship between temperature and infrared

All object emit infrared.
An object with higher temperature emits more infrared.



Temperature of black body and spectrum of emitted light

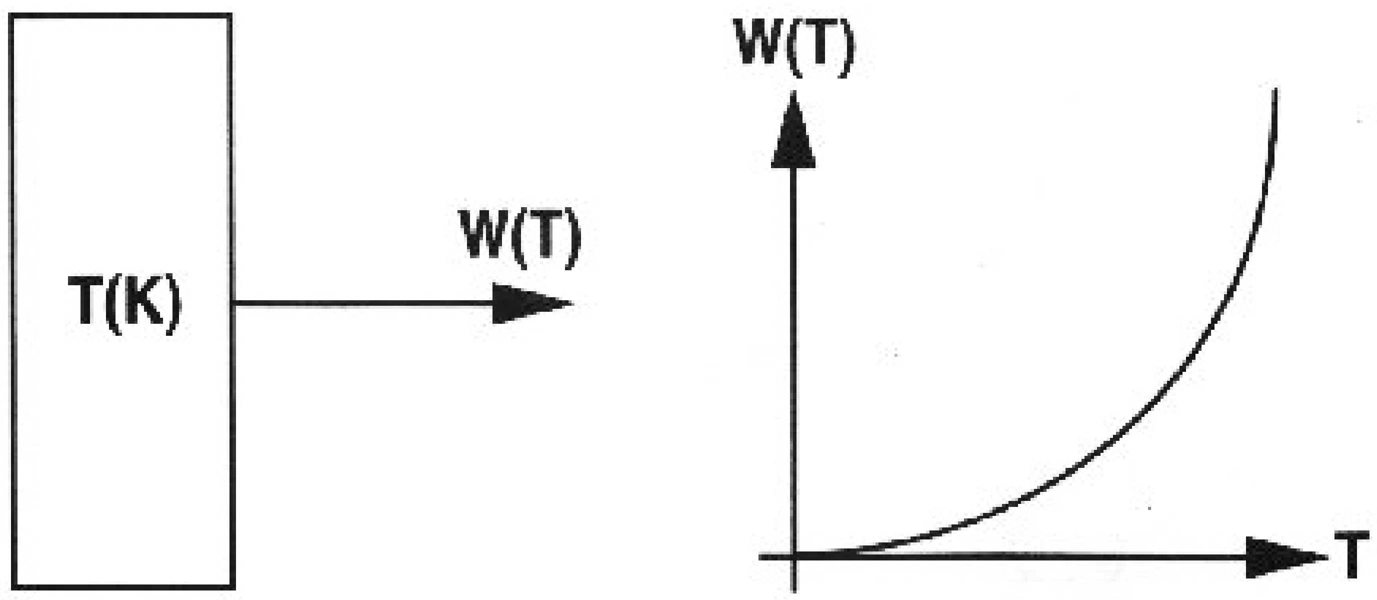
7.Measurement of temperature distribution

Relationship between temperature and infrared

$$W(T) = \sigma T^4$$ (Black body emission)

σ : Stefan-Boltzmann constant (5.637×10^{-12} W／$cm^2 \cdot K^4$)

K (Kelvin) = ℃+273

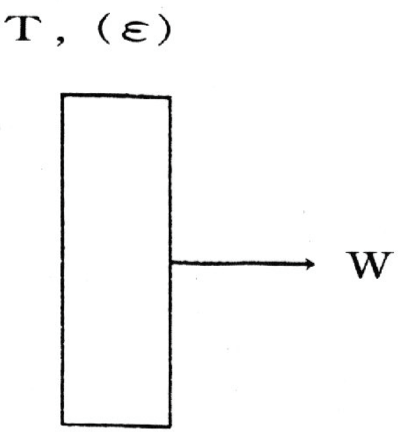


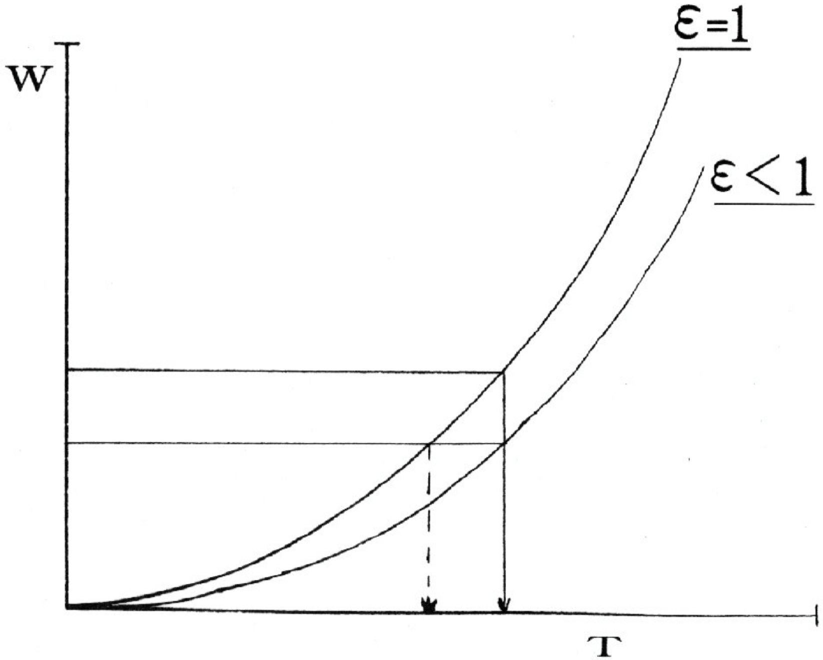
7.Measurement of temperature distribution

Relationship among temperature, infrared and emissivity

$$W = \underline{\varepsilon}\,\sigma\,T^4$$

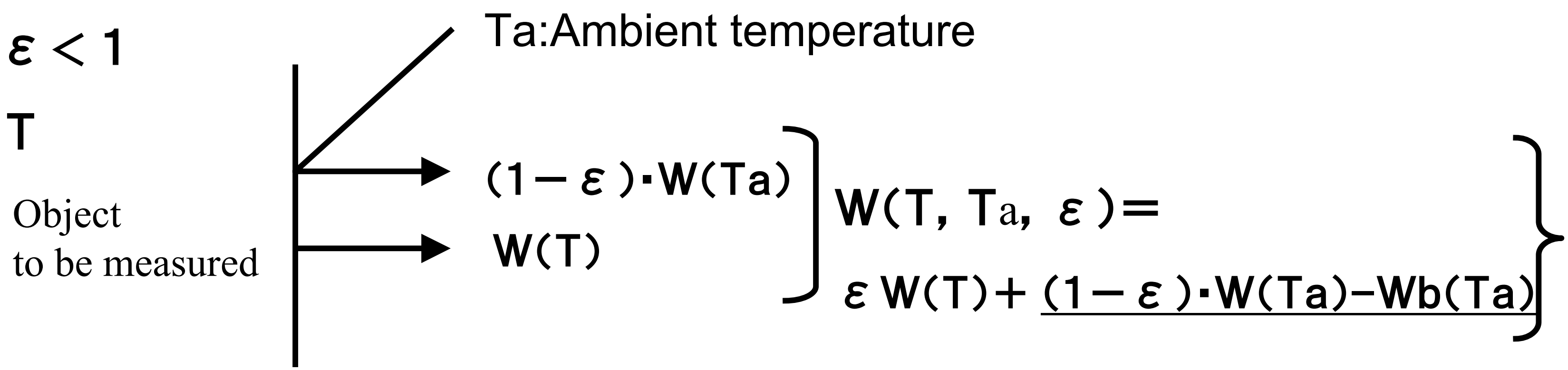
W = infrared energy
<u>ε = emissivity</u>
σ = constant
T = absolute temperature
(T = t + 273)





7.Measurement of temperature distribution

Temperature measurement and ambient temperature correction



8.Emissivity

<The idea of emissivity>

(1)For example, if a temperature of an object having the temperature of 100℃ is taken from a short distance using a thermography, actual measurement will be less than 100℃. That is caused by the emissivity of that object.

(2) The emissivity of most objects is less than 1.0.

(3) The emissivity is not related to the temperature of an object but it is related to the infrared energy radiated from that object.

(4) The emissivity (ε) is defined as (energy radiated by an object) ÷ (energy radiated by the blackbody).
Accordingly, $W = \varepsilon \sigma T^4$.

(5) When measuring the temperature distribution, it is not necessary to worry too much about emissivity. When reading the image data, however, it is necessary to take the difference of the surface emissivity (and reflectivity) into consideration.

8.Emissivity

■Emissivity characteristic

Infrared, which is radiated from the object for temperature measurement, has a special emissivity characteristics in addition to the normal emissivity.

■Normal emissivity characteristic

Dependence	Characteristics
Material	It is determined as an electromagnetic physical property value of the material.
	It is also related to the color.
Surface condition	Rougher the surface is, greater the emissivity will be. It will be small in case of mirror finished surface.
	Even if the material is the same and the temperature is the same, it will be measured as an apparent temperature difference if the surface roughness is different.
Rust on metal surface	Deeper the rusting is, greater the emissivity will be.
	Even if the metal type is the same and the temperature is the same, it will be measured as an apparent temperature difference if the level of rusting is different.

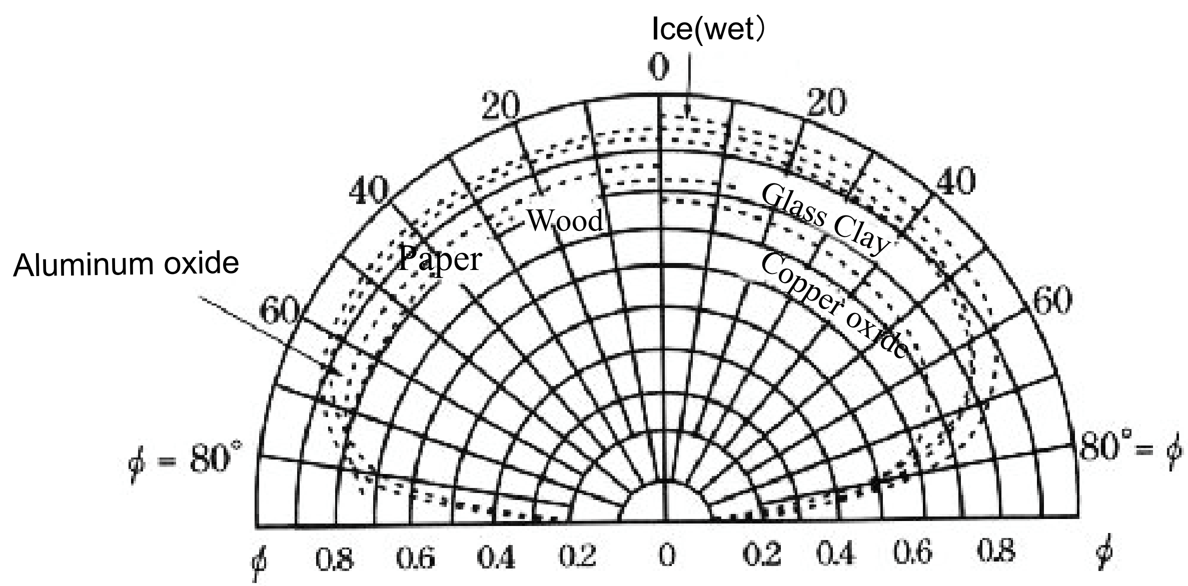
8.Emissivity

■Special emissivity characteristics

Dependence	Characteristics
Temperature	As a general tendency, as the temperature of an insulation material goes up, emissivity becomes smaller. In case of metal, as the temperature goes up, emissivity also goes up.
	When the temperature changes drastically (approximately 100℃), temperature cannot be measured correctly unless emissivity correction value is changed.
Cavity radiation at holes and corners	Affected by multi-path reflection, holes and corners will demonstrate cavity radiation, and emissivity will become large. The smaller and deeper the hole is, the greater the emissivity is.
	Even if an object has even temperature distribution and small emissivity, the hole part will have greater emissivity resulting in higher temperature reading.

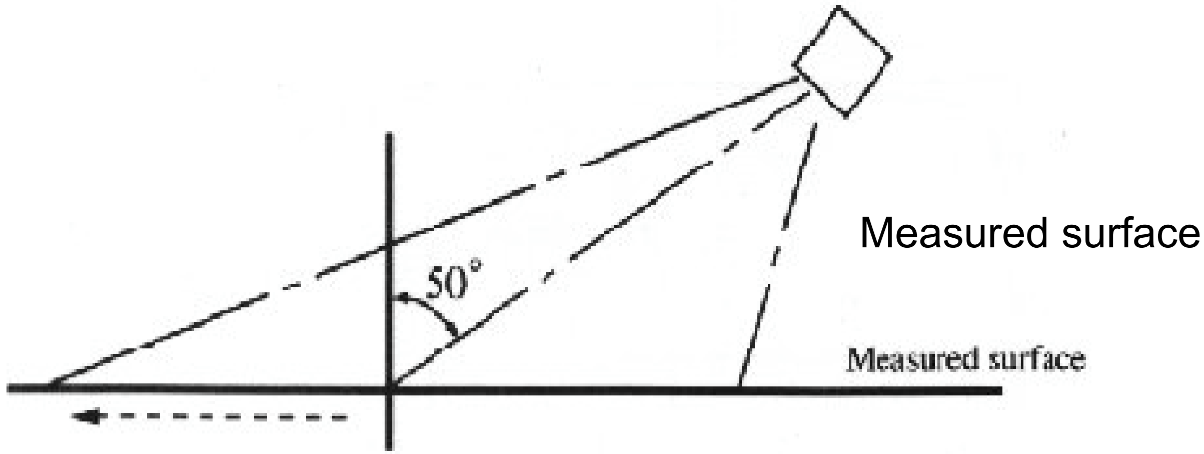
8.Emissivity

■Special emissivity characteristics

Dependence	Characteristics
<u>Measured angle</u>	As a general tendency, emissivity stays the same from perpendicular to approximately 50°. After approximately 50°, emissivity starts to go down, and once it passes approximately 60° point, it goes down drastically. 

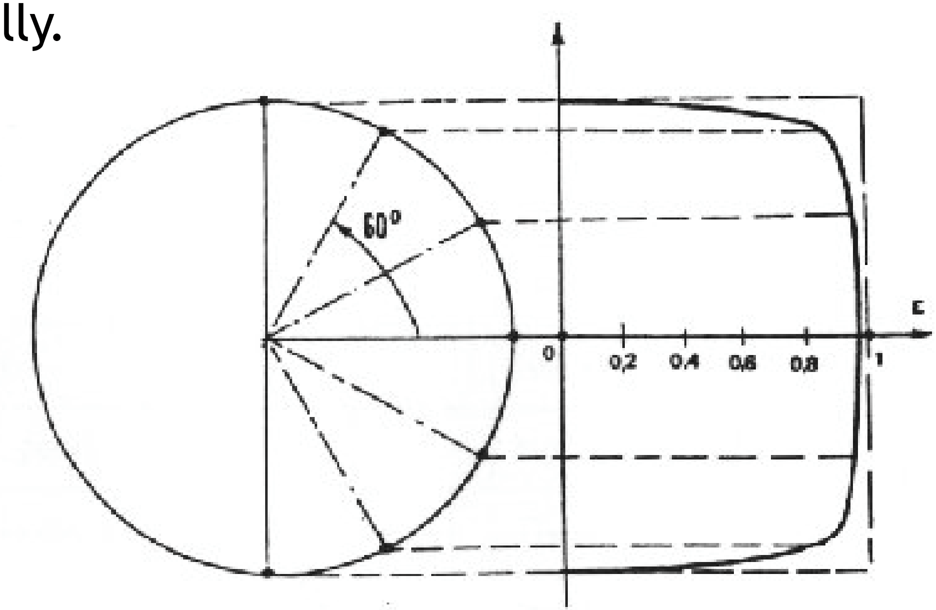
8.Emissivity

■Special emissivity characteristic

Dependence	Characteristics
Measured angle	If it is unavoidable to measure from an angled position, you need to be careful as the measured surface toward you (measured angle is gentle) will indicate higher temperature and the measure surface away from you will indicate lower temperature.  Temperature reading will be smaller superficially as the measured surface is farther from you.

8.Emissivity

■Special emissivity characteristics

Dependence	Characteristic
Measured angle	When measuring a cylindrical surface, the range in which measurement can be made without much angle dependency of emissivity is approximately 80% of the cylinder diameter. Beyond that point, superficial temperature reading will drop drastically. 

9.Characteristics of short wave and long wave

■Measurement inside the building

In normal measurement,
you need not worry about the detected wavelength in most cases.

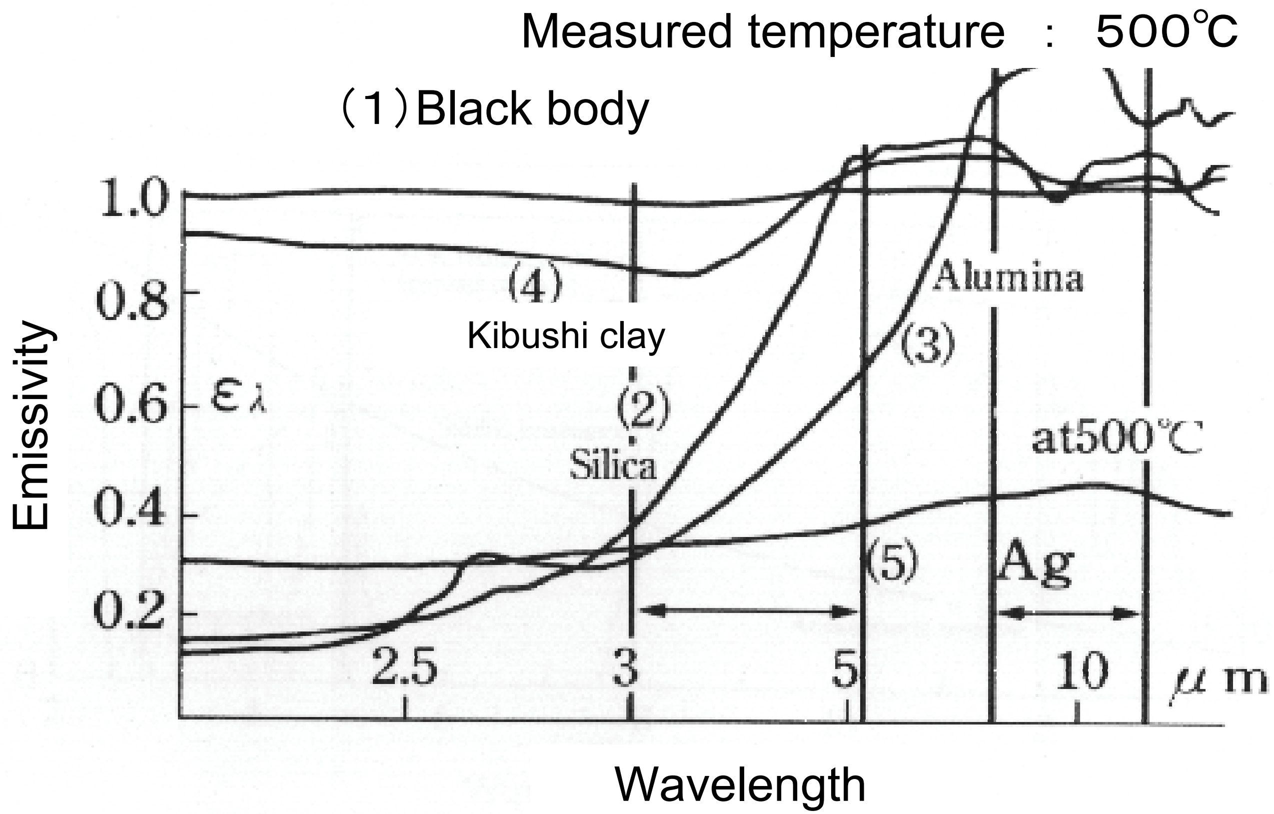
■Measurement

You need to be careful as the impact of
the detector wavelength will be different.

Compared item	Short wavelength(SW)	Long wavelength(LW)
Detected wavelength	3～5 μm	8～14 μm
Impact of sunlight reflection	Large	Almost none
Impact of ambient reflection	Small	Large
Impact of low temperature reflectio	Small	Large
Atmospheric attenuation	Vulnerable	Not vulnerable
Glass transmission	Relatively good	No transmission
Measurement inside a container	Measureble through a sapphire window.	Germanium, etc.
Impact of gas flare	Large	Relatively small

9.Characteristics of short wave and long wave

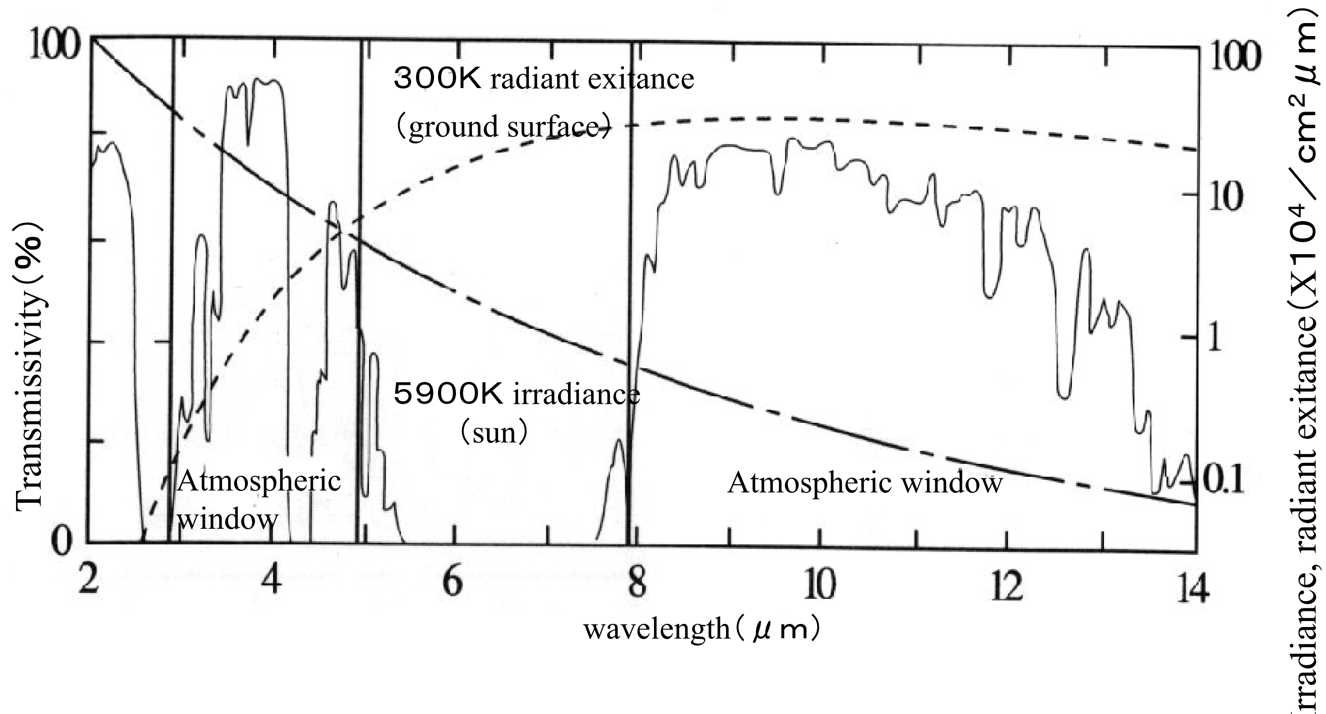
Spectral emissivity of various material



9.Characteristics of short wave and long wave

Atmospheric transmission and radiant energy characteristics of the sun and ground surface

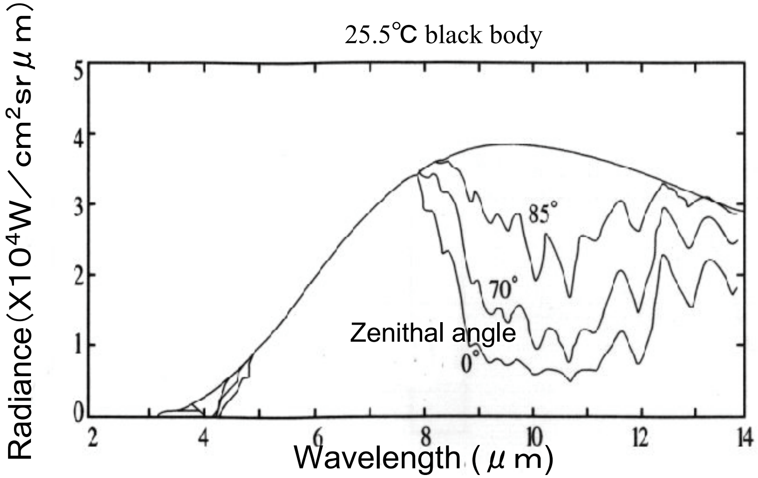
	Short wavelength(3~5 μ m)	Long wavelength(8~14 μ m)
Radiant energy of the sun	Large	Small
Radiant energy of ground surface	Small	Large



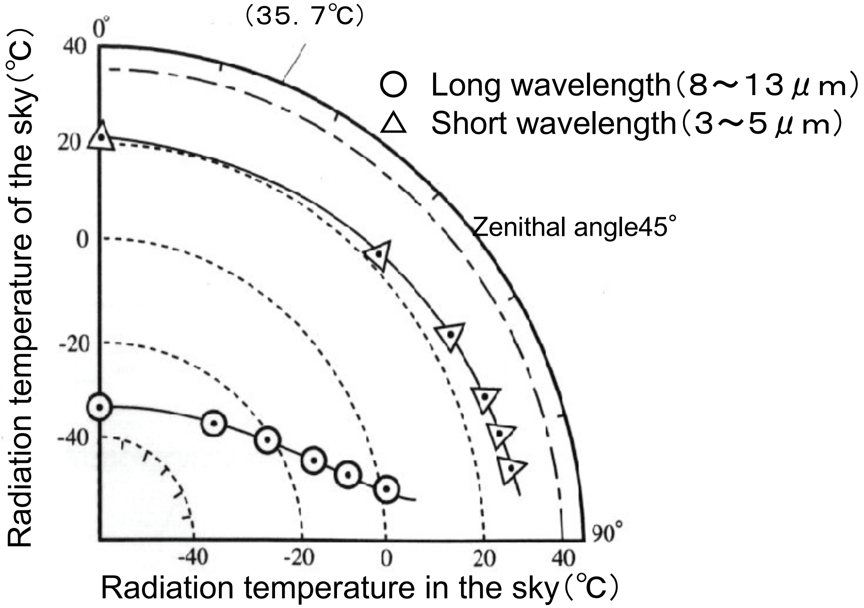
9.Characteristics of short wave and long wave

■Radiant energy and radiation temperature of the sky

	Short wavelength(3～5μm)	Long wavelength(8～14μm)
Radiant energy of the sky	Large	Small
Radiation temperature of the sky	High	Low
Impact of reflection of the sky	Small	Large



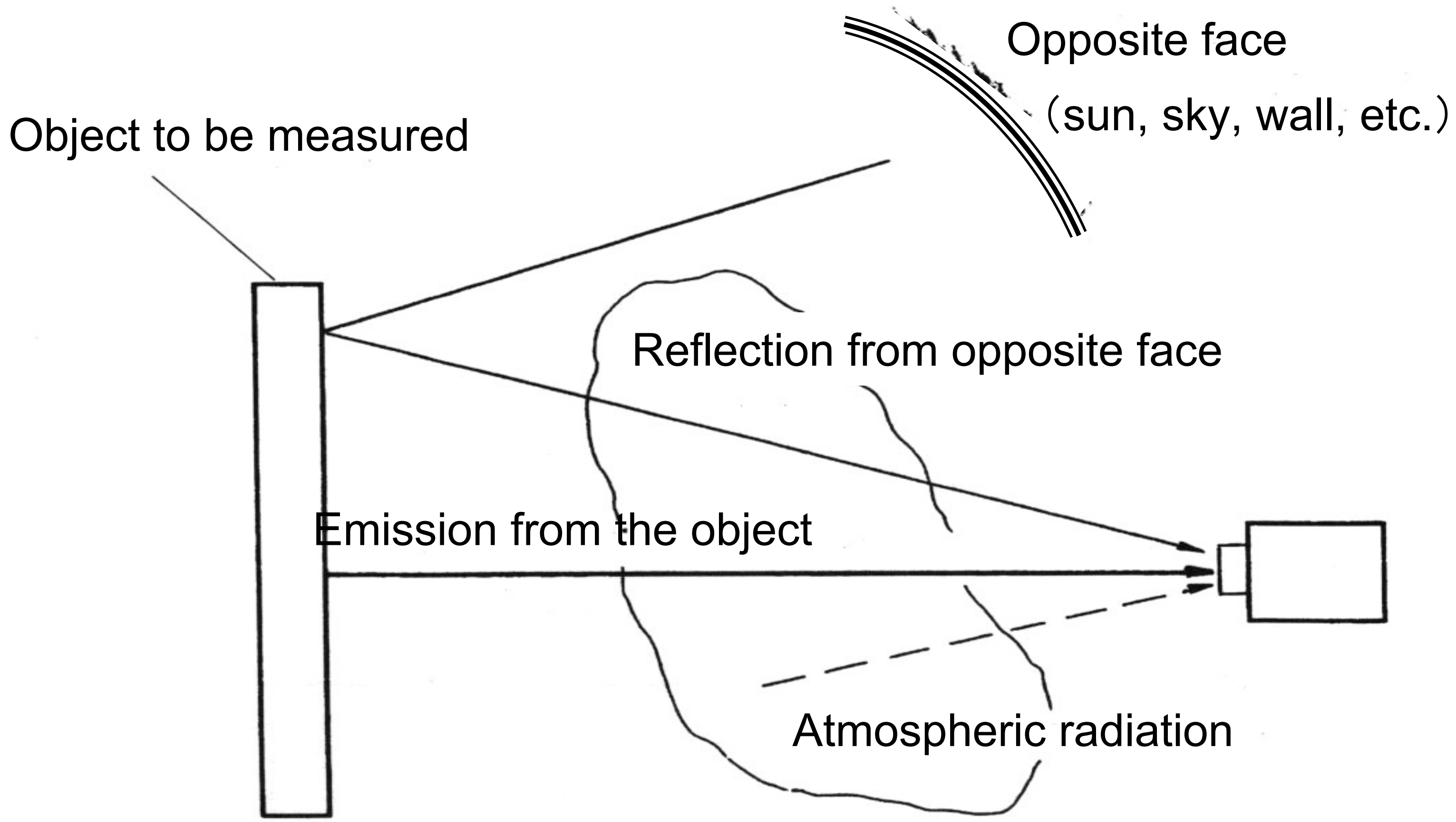
Radiant energy of the sky on a clear day



Angular characteristics of radiation temperature in the sky at zenithal angle

9.Characteristics of short wave and long wave

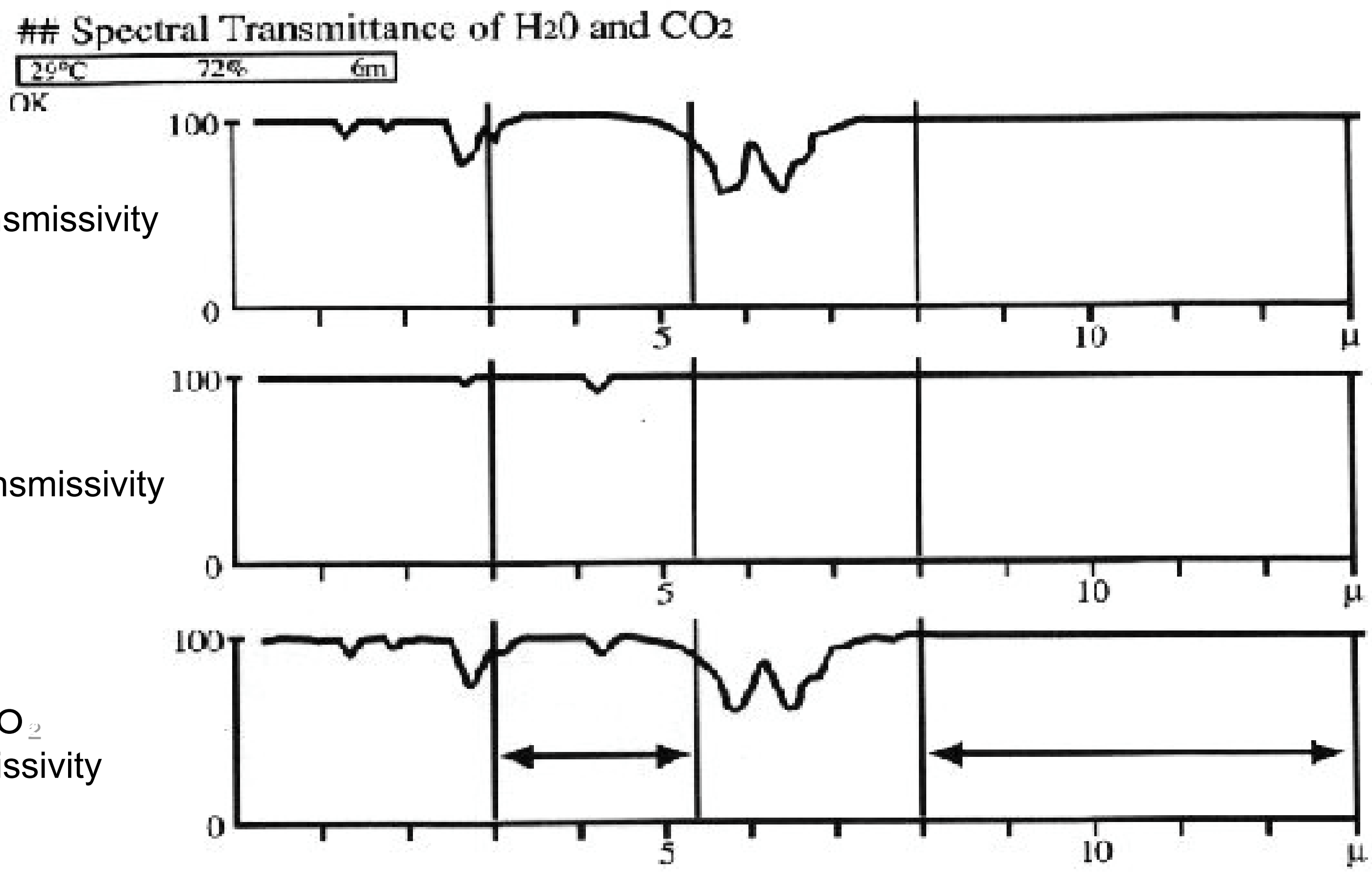
〈Transmission path of infrared radiate energy in the case of outside measurement〉



Atmospheric absorption and scattering in the transmission path

9.Characteristics of short wave and long wave

Atmospheric transmission characteristics（6m）



H_2O transmissivity

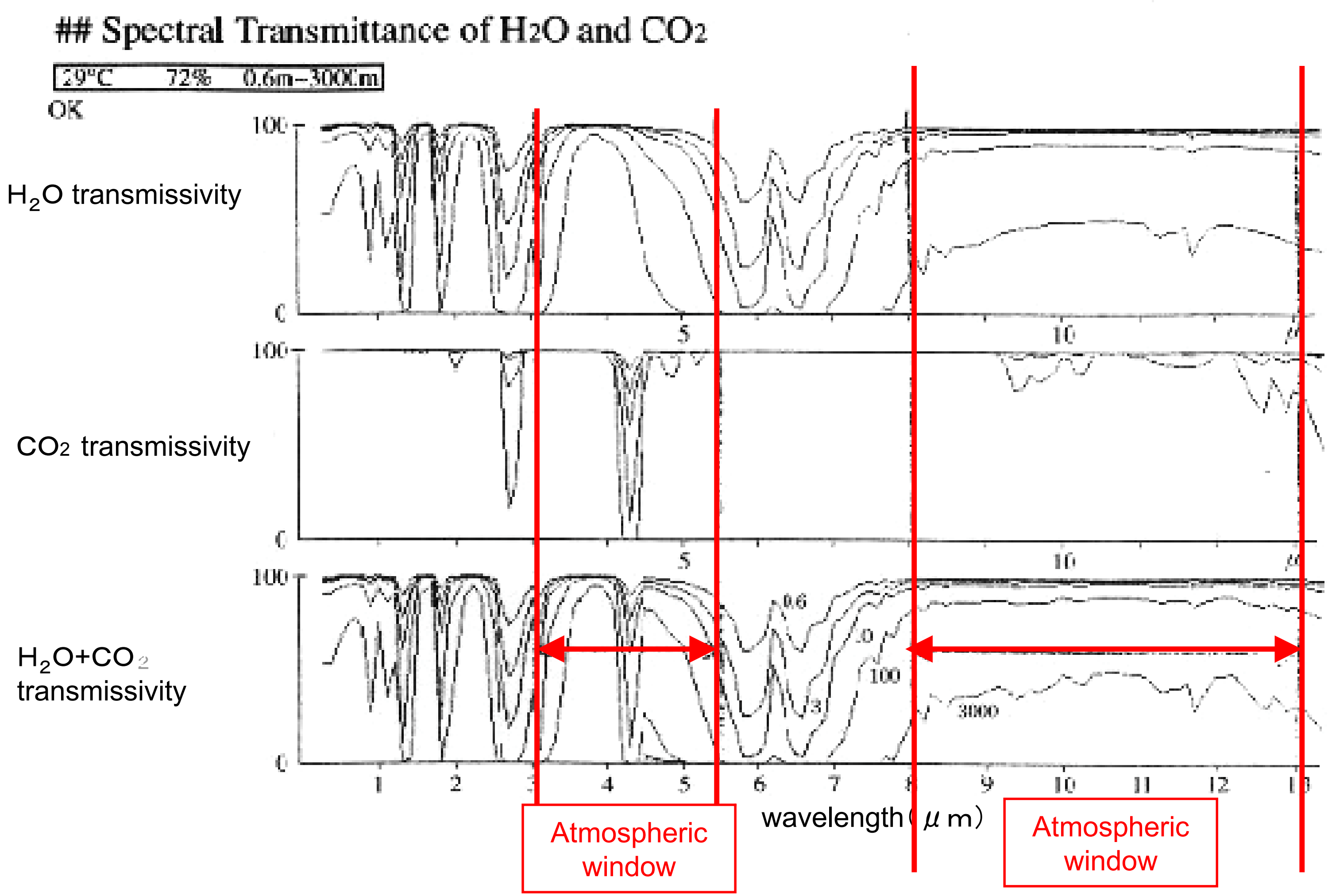
CO_2 transmissivity

H_2O+CO_2 transmissivity

Wavelength（μm）

9.Characteristics of short wave and long wave

Atmospheric transmission characteristics（60cm～3km）



10.FOV & Spatial Resolution

Spatial resolution is very important for accurate temperature measurement

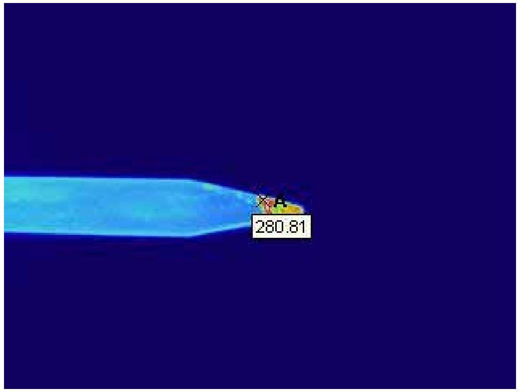


Photo 1

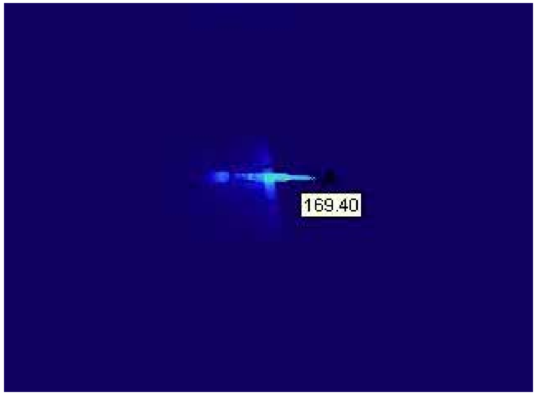
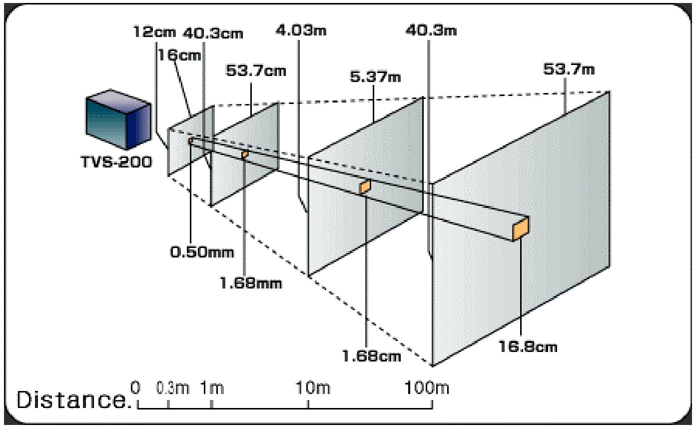


Photo 2



Distance and FOV size

When TVS-200 is located 1 meter away from object, size of FOV is 53.7cm horizontal and 40.3cm vertical, spatial resolution or size of one pixel is 1.68mm

Both photo 1 and 2 are thermal image of soldering iron of 8mm diameter.

Photo 1 was taken at 30cm distance, which is larger than spatial resolution.

Photo 2 was taken at 2 meter distance, which failed to fill spatial resolution and displays much lower temperature.

11.Focus

Focus is very important for accurate temperature measurement

Photo 1

Photo 2

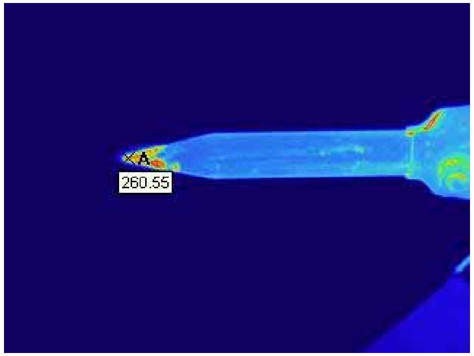


Photo 3

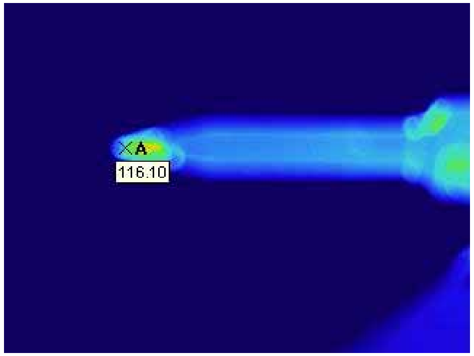


Photo 4

Photo 1 and 2 are thermal image of a man.
When focus is correct as shown in photo 1, edge of object is sharp
When out of focus as shown in photo 2, image is blur and fuzzy.
Photo 3 and 4 are thermal image of soldering iron.
When focus is correct as shown in photo 3, TVS can get maximum amount of infrared energy from an object, which leads to accrete temperature measurement.
When out of focus as shown in photo 4, TVS can get less amount of energy, which leads to inaccurate temperature measurement.

12.Precautions in measurement

(1)Try to hold the infrared camera facing straight toward the object to be measured.

If not possible, hold the camera within 50° angle.

(2)Bring the infrared camera as close as to the object to be measured as possible.

(3)Take measurement under correct focus.

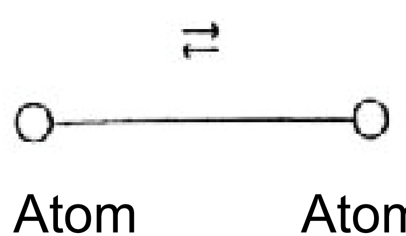
(4)Take measurement by taking reflection from the ambient or the opposite face of the object into consideration.

13.Others : Emission of infrared

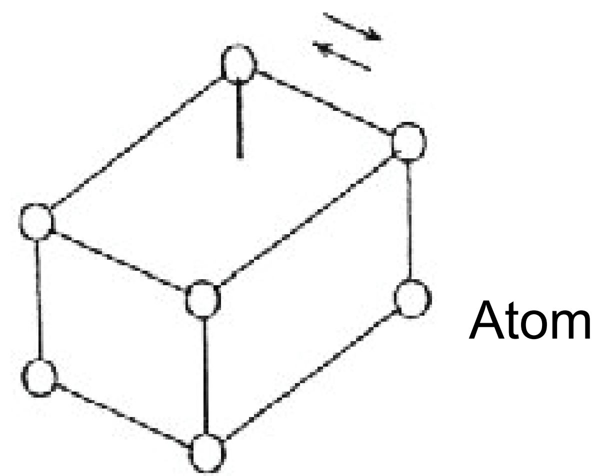
(1)Radiation of infrared is caused by;

① molecular vibration where the atoms comprising the molecules vibrate.

② grid vibration where grid of molecular structure vibrate.



Molecular vibration



Grid vibration

13.Others: Emission of infrared

（2）In order to increase infrared emission;

① Heat with a heater

② Apply mechanical stress

$$\Delta T = -K_m \cdot T \cdot \Delta \sigma$$

③ Cause friction

④ Illuminate microwave（microwave oven）

⑤ Cause electromagnetic induction

⑥ Cause resistance heating

14.Others : Various measurements utilizing infrared

（1）Temperature measurement

（2）Stress measurement　：　Adiabatic compression ⇒ Temperature up
Adiabatic pull ⇒ Temperature down

（3）Moisture measurement　：　Utilizing absorptivity

（4）Visualization of flow

（5）Utilization of difference in emissivity

（6）Film thickness gauge　：　Utilizing transmissivity

（7）Utilization of thermal inertia