Measuring temperature

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The simplest definitions of temperature according to thermodynamics are the 'degree of hotness' of a body, or a measure of 'heat density' within a body. More precisely, temperature is the potential for heat transfer, or a measure of the tendency of a body to give up heat to its surroundings. A convenient operational physical definition is that it is a measure of the average translational kinetic energy associated with the random microscopic motion of atoms and molecules within a substance. Heat flows from a region of high temperature towards a lower temperature region.

The relationship of temperature to molecular motion is described by kinetic theory. Temperature is not proportional to the total internal energy, but only to the kinetic energy component. Therefore, it is possible for two objects of different material to have the same temperature, but differing total internal energy. Monatomic gaseous substances represent a collection of mobile point masses, and temperature is simply associated with mean kinetic energy. Faster atoms striking slower atoms at the boundary of the substance in elastic collisions increase the velocity of the slower atoms and decrease the velocity of the faster atoms, resulting in energy transfer from the higher to lower temperature region. For polyatomic or molecular substances, rotation and vibration around inter-atomic bonds contribute to total kinetic energy in addition to translational movement. In these substances, temperature is related only to the mean translational component of internal kinetic energy.

Heat and temperature

When two bodies of differing temperature are placed in thermal contact, internal energy is exchanged until the temperature of the two is equalized. The amount of energy transferred is equal to the amount of heat exchanged. The amount of heat energy required to alter the temperature of a body depends on the heat capacity. Heat capacity depends on the amount of material and its individual properties (Figure 1). Heat transfer from a body broadly occurs by three mechanisms: conduction, convection, and radiation. Additional significant heat input is required to effect a change of state from solid to liquid and from liquid to gas, even if the temperature of the substance remains the same. This is known as latent heat of fusion or vaporization, respectively, and explains why the continued input of energy is necessary to boil water even if the temperature remains at a constant 100°C. Using water as an

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Heat capacity

Heat capacity is a physical property of a body (e.g. human body) not of a uniform material

Heat capacity (J/K) = heat transferred / temperature rise

If the body is a homogeneous single material, then specific heat capacity is:

Specific heat capacity (J/K/kg) = heat capacity / mass

Specific heat capacity is a property of a material, not of a body

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example, the specific latent heat of fusion is 334 kJ/kg and the specific latent heat of vaporization is 2260 kJ/kg. This illustrates why evaporation from the respiratory tract represents a significant source of heat loss from the anaesthetized patient.

Temperature scales

Fahrenheit scale (°F): Daniel Fahrenheit arbitrarily decided that the freezing and boiling points of water would be separated by 180°. He calibrated a mercury thermometer in freezing water, marking this 32°, and then in boiling water, marking this 212°. He then placed 180 evenly spaced marks between the calibration points.

Celsius scale (°C): Anders Celsius arbitrarily decided that the freezing and boiling point of water would be separated by 100°. Initially he fixed the freezing point at 100°. The scale was later inverted with 0° as freezing point, and 100° as boiling point.

Kelvin thermodynamic temperature scale (KTTS): Lord Kelvin defined an absolute thermodynamic scale of temperature as the temperature difference between absolute zero and the triple point of water divided by 273.16. The triple point for a substance is the temperature at which the solid, liquid and vapour phases are in equilibrium. Temperatures measured from absolute zero are expressed in kelvin, and those above the freezing point of water (273.15K) in degrees Celsius. Temperature differences on either scale are given in kelvin, the SI unit of temperature difference. One degree kelvin is equal in magnitude to one degree Celsius.

International Temperature Scale of 1990 (ITS-90): modern thermometers are calibrated to ITS-90. The triple point of water (273.16K or 0.01°C) is the most important and readily achievable thermometric fixed point on both the kelvin and ITS-90 scales. The full ITS-90 scale is defined from upwards of 0.65K using 17 fixed points. Some examples of fixed points on the ITS-90 scale are given in Figure 2.

Some fixed points on the International Temperature Scale of 1990 (ITS-90)

Fixed point	Temperature (K)	Substance	Physical property
5	24.5561	Neon	Triple point
6	54.3584	Oxygen	Triple point
7	83.8058	Argon	Triple point
8	234.3156	Mercury	Triple point
9	**273.16**	**Water**	**Triple point**
12	505.078	Tin	Freezing point
13	692.677	Zinc	Freezing point
14	933.473	Aluminium	Freezing point
15	1234.93	Silver	Freezing point
16	1337.33	Gold	Freezing point
17	1357.77	Copper	Freezing point

The freezing point of a substance is the temperature at a pressure of 101.325 kPa, at which the solid and liquid phases are in equilibrium

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Thermometer definition

A thermometer is a device for measuring the temperature of a substance or body. The device uses a reliable, reproducible and quantifiable change in a physical property of a substance in response to temperature. Thermometers may be classified broadly into contact and non-contact devices. Contact devices must be placed in direct contact with the medium or body to be measured, and must reach thermodynamic equilibrium with the medium. Non-contact devices measure temperature at a varying distance, without the need for direct thermodynamic contact.

Thermometers may also be classified according to the physical property underlying their function (Figure 3). Factors influencing the choice of device for a particular measurement include temperature range for the device, size and accuracy. In general, a larger contact thermometer takes longer to reach thermal equilibrium than a smaller device, and accurate measurement of temperature takes longer.

Thermometers utilizing a change in state

Liquid crystals exist in a distinct phase of matter between solid and liquid. They consist of rod-shaped molecules, and have a tendency to form spiral or ‘chiral, nematic’ arrangements, like the steps of a spiral staircase. The pitch of the helix is the distance taken to

Classification of thermometers

Physical

- Change of state device (e.g. liquid crystal)
- Change in gas, liquid or metal density (e.g. constant volume gas thermometer, liquid alcohol or mercury in glass, Galileo, bimetallic)
- Bourdon

Electrical

- Change in electrical resistance (e.g. resistance temperature detector (metal), thermistor)
- Change in emf (electromotive force) output (e.g. thermocouple)
- Non-contact devices (e.g. thermopile, optical pyrometer, radiation thermometry)

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