Measuring temperature

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Abstract

In the perioperative period patients tend to lose heat and become hypothermic. An understanding of the causes and prevention of heat loss is therefore important to the anaesthetist. Heat and temperature are measures of energy. Heat is a measure of the total kinetic energy (joules, J) of a body, and depends on the size of the body and its specific heat capacity. Temperature is a measure of the average kinetic energy, and describes the potential for heat transfer from a body at high temperature to one at lower temperature until both bodies reach equilibrium at the same temperature. Temperature is measured on a scale (e.g. Fahrenheit, Celsius or Kelvin) that is defined by fixed points related to predictable physical events (e.g. the freezing point, steam point and triple point of water).

Keywords Fixed points; heat; temperature; thermometer; thermometric properties

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Learning objectives

After reading this article, you should be able to:
- define heat and temperature
- describe fixed points and temperature scales in common use
- explain the principles of action of thermometers in common use, with the particular advantages and limitations of each type

Introduction

Humans are **homeothermic**, that is, they control core body temperature within a narrow range (36.8 ± 0.4°C). When a patient undergoes surgery under anaesthesia they will inevitably lose heat due to vasodilatation, exposure of tissues, cold intravenous fluids and ventilation with dry cold gases. The mechanisms of heat loss are: **convection, conduction**, **radiation** and **evaporation**. It is important for the anaesthetist to make every effort to minimize heat loss as hypothermia has many adverse effects, including impairment of cardiac output, oxygen delivery, coagulation and drug metabolism. Further, shivering in the postoperative period increases pain and oxygen consumption.

It is therefore very important to monitor patients' body temperature to diagnose hypothermia or hyperthermia (due to, for example, fever or malignant hyperpyrexia). **Core body temperature** can be measured in the pulmonary artery, oesophagus, nasopharynx and tympanic membranes, while **peripheral body temperature** can be measured sublingually, in the axilla, rectum, bladder and on the forehead, and is usually within ± 0.5°C of core temperature.

Heat loss can be minimized by:
- maintaining theatre ambient temperature >22°C
- use of blood/fluid warmers
- pre-warming intravenous fluids in warming cabinets
- forced air convection heaters/blankets
- warming mattresses
- hats for small children and babies.

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Heat and temperature

Heat is a measure of energy and therefore has the SI unit **joule** (**J**) (and non-SI unit calorie: 1 calorie = 4.186 KJ). It is the quantity of thermal energy in a substance and represents the total kinetic energy of the molecules. The total amount of heat energy in a body depends on the mass of the body and its specific heat capacity. The **heat capacity** of a body is the heat required to produce a unit temperature rise, and has the SI unit joule per kelvin (JK^{-1}). **Specific heat capacity** is the heat capacity per unit mass of a substance, and has the SI unit joule per kelvin per kilogram ($JK^{-1}Kg^{-1}$).

Temperature is the degree of hotness (or coldness) of a body. It is a measure of the average kinetic energy of the molecules within a substance, although individual molecules will have a wide range of kinetic energy. In a solid the molecules vibrate faster and with greater amplitude when heated. In liquids and gases where the molecules are free to move, they move with higher velocity when heated, resulting in more frequent collisions with each other and with the vessel walls. Temperature also represents the tendency of a substance to lose or gain heat relative to its surroundings. Heat tends to flow down a temperature gradient from a hot body towards a cold one, and given time this process will continue until they are both at the same temperature.

Temperature scales

In order to establish a temperature scale it is necessary to make use of fixed points. A **fixed point** is the single temperature at which a particular physical event always occurs, for example:
- **The ice point**: The temperature at which ice exists in equilibrium with water at standard pressure (101.3 kPa). This is designated 0°C or 32°F.
- **The steam point**: The temperature at which pure water exists in equilibrium with its vapour at standard pressure, that is, the temperature at which the saturated vapour pressure of pure water equals atmospheric pressure. This is designated 100°C or 212°F.
- **The triple point of wate**r: The temperature at which pure water, water vapour and ice can exist in equilibrium. This is designated 0.01°C and can only occur at 611 Pa (0.006 atm.).

The **Fahrenheit scale** was devised by German physicist Daniel Gabriel Fahrenheit in 1724. There is no particular logic to the scale and its evolution, and it has been revised several times. Fahrenheit defined the temperature of a mixture of ice, salt and sal ammoniac (ammonium chloride) as 0°F, the ice point as 32°F and the boiling point of water as 212°F; and divided the ice and boiling points into 180 divisions or 'degrees'

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(°). His temperature scale was widely adopted because it was used in his accurate and commercially successful mercury thermometers.

The **Celsius scale** was devised by Swedish astronomer Anders Celsius shortly after Fahrenheit's death in 1736. Celsius divided the fixed points of the boiling and freezing points of water into 100° (hence until 1948 this was sometimes also called the 'centigrade scale'). Celsius originally represented the boiling point as 0°C and the freezing point as 100°C; but this convention was reversed after his death by one of his students. It became known at the 'Celsius scale' from the early part of the 19th century, but was only officially recognized after the 9th Conference on Weights and Measurements in 1948.

The **Kelvin scale** was proposed by Irish physicist William Thomson, First Lord Kelvin. It is also called the absolute or thermodynamic scale. His scale uses the fixed points of **absolute zero** and **the triple point** of water. Absolute zero is defined as the theoretical temperature at which the molecules in a substance have no kinetic energy. Absolute zero has been approached experimentally, but is impossible to achieve and therefore cannot be measured directly. The scale has the same intervals as the Celsius scale (1°C = 1 K) with absolute zero representing 0 K and the triple point of water representing 273.16 K; therefore 1 K (kelvin) is defined as the fraction 1/273.16 of the triple point of water.*

The **International Temperature Scale of 1990 (ITS-90)** is the current standard used to calibrate modern thermometers. ITS-90 ranges from 0.65 K to >1300 K and uses several fixed points including the triple points of water (273.16K), neon (24.56K), oxygen (54.36K), argon (83.8K) and mercury (234.3K); and the freezing points of tin (505.1K), aluminium (933.5K), gold (1337.3K) and copper (1357.8K).

The relationship between the Kelvin, Celsius and Fahrenheit scales is shown (Table 1).

Comparison of the Kelvin, Celsius and Fahrenheit scales

Fixed point	Temperature scale		
	Celsius (°C)	Fahrenheit (°F)	Kelvin (K)
Absolute zero	−273.15	−459.7	0
Freezing point of water	0	32	273.15
Triple point of water	0.01	32.018	273.16
Average room temperature	20	68	293
Average body temperature	37	98.6	310.15
Boiling point of water	100	212	373.15

Table 1

Thermometers and thermometric properties

A **thermometer** is a device for measuring the temperature of a substance or body. All thermometers rely on a **thermometric property** (i.e. a physical property that changes in a known, predictable, and reliable way with temperature). Ideally there should be a simple linear relationship between temperature and the thermometric property (e.g. the length of a mercury column), although some relationships are non-linear (e.g. thermistor). Based on their mechanism of action, thermometers can be classified as non-electrical or electrical (Box 1).

Non-electrical thermometers

Touch has the advantage of needing no equipment, but is extremely inaccurate and does not provide a quantitative measurement.

Liquid expansion thermometers consist of a sealed glass capillary tube with a bulbous reservoir at one end which is filled with a liquid (usually **mercury** or **alcohol**) that undergoes linear expansion within a certain temperature range when heated. As the liquid warms it increases in volume and is forced up the capillary tube alongside a calibrated scale from which the temperature can be read. There is usually a constriction between the bulb and the capillary tube which delays the return of the liquid to the bulb on cooling, allowing the reader time to read the maximum temperature, after which the liquid may be returned to the bulb by shaking the thermometer. Liquid expansion thermometers are used to measure body temperature, usually from the oral, axillary and rectal regions. The effective range for ethanol is −100°C to 50°C (melting point −114°C, boiling point 78°C) and for mercury is −10°C to 350°C (melting point −39°C, boiling point 357°C); however, the range can be extended by adding gas or liquids such as toluene to the mercury. Accuracy depends on the diameter and length of the capillary tube. Mercury thermometers for clinical use normally have a scale range 35°C−42°C.

Advantages:

- simple to use and read
- low cost
- accurate over body temperature range.

Disadvantages:

- glass is fragile and can break, causing injury and toxicity if mercury used
- Slow response time (2−3 minutes)
- limited range due to boiling and freezing point of alcohol and mercury, respectively.

Classification of thermometers

Non-electrical

- Touch
- Liquid expansion thermometers (mercury, alcohol)
- Gas thermometers
- Bimetallic strip thermometers
- Liquid crystal thermometers
- Infrared thermometers

Electrical

- Resistance thermometers
- Thermistors
- Thermocouples

Box 1

* The SI unit Kelvin (K) should never be expressed or typeset as 'degree kelvin' or '°K'; in contrast to 'degree Celsius (°C)' and 'degree Fahrenheit (°F)'.

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