Much of anaesthetic practice is underpinned by physics, yet many struggle when studying the subject. This book has been written with the aim of helping those who have long since parted company with physics.

The content is based on the FRCA syllabus making Physics in Anaesthesia ideal for trainee anaesthetists, as well as for operating department practitioners and anaesthetic nurses. In addition, clinical science and engineering students will appreciate the linking of theory and practice. Physics in Anaesthesia gives a complete and structured overview:

- Explanations start from first principles
- Simple everyday examples are used to illustrate core concepts
- Clinical examples highlight the applications of physics in anaesthesia
- Worked examples and helpful diagrams develop understanding
- Revision aids include chapter summaries, key definitions and MCQs/SBAs

“Having struggled through the trials of the exam, I wish that this book had been available at the time. I am sure that this book will quickly be viewed as ‘indispensable’ by trainee anaesthetists.”
Dr Mike Cunningham

“Very useful chapters containing the sort of information I had to spend a lot of time trawling through other textbooks and the net to find! Thorough but concise with clear diagrams: an excellent revision aid.”
Dr Anna Barrow (ST3)

“Concise and easy to read: a great help in revision. Helpful SBAs & MCQs at the end of each chapter are most welcome.”
Dr David Golden (ST5)

“This book is a must if you are looking to explore the marvellous science associated with anaesthesia: first-rate explanations and the diagrams are fantastic.”
John Denbigh (Senior ODP)

“I thoroughly recommend this clear and accessible text to my students.”
Dr Hazel Screen (Senior Lecturer, Biomedical Engineering)
“If you can’t explain it simply, you don’t understand it well enough.”

Albert Einstein
# Contents

Foreword ................................................................................................................................. xiii  
Preface ........................................................................................................................................ xv  
Acknowledgements .................................................................................................................. xv  
About the authors ................................................................................................................... xvi  
Abbreviations ........................................................................................................................ xvii  

## 1 Atoms and matter ............................................................................................................. 1  
1.1 The atom ......................................................................................................................... 1  
1.2 States of matter ................................................................................................................ 3  
1.3 Phase diagrams ................................................................................................................ 5  
Single best answer questions ............................................................................................... 8  
Multiple choice questions .................................................................................................... 8  

## 2 Simple mechanics ............................................................................................................. 9  
2.1 Force, velocity and acceleration ..................................................................................... 9  
2.2 Force, weight and pressure ............................................................................................. 11  
2.3 Viscosity .......................................................................................................................... 12  
2.4 Surface tension and wall tension .................................................................................... 13  
2.5 Surfactant and surface tension ....................................................................................... 15  
Single best answer questions ............................................................................................... 18  
Multiple choice questions .................................................................................................... 19  

## 3 Energy and power ............................................................................................................ 20  
3.1 Work and energy ............................................................................................................. 20  
3.2 Efficiency and power ...................................................................................................... 21  
3.3 Work of respiration ......................................................................................................... 22  
3.4 Compliance ..................................................................................................................... 24  
3.5 Work done during spontaneous breathing .................................................................... 25  
3.6 Flow characteristics during breathing ........................................................................... 26  
3.7 Work done by the heart ................................................................................................. 27  
Single best answer questions ............................................................................................... 29  
Multiple choice questions .................................................................................................... 29  

## 4 Temperature and heat ..................................................................................................... 30  
4.1 Heat ................................................................................................................................. 30  
4.2 Temperature .................................................................................................................... 31  
4.3 Transfer of heat .............................................................................................................. 32  
4.4 Black-body radiation ..................................................................................................... 34  
4.5 Regulation of body temperature .................................................................................... 36  
4.6 Measuring temperature ................................................................................................. 37  
4.7 Laws of thermodynamics ............................................................................................... 41  
Single best answer questions ............................................................................................... 44  
Multiple choice questions .................................................................................................... 45
### Contents

#### 5 Waves
- 5.1 Properties of waves ................................................................. 46
- 5.2 Sound waves ........................................................................... 48
- 5.3 Electromagnetic waves ........................................................ 49
- 5.4 Simple harmonic motion ....................................................... 53
- 5.5 Resonance and damping ....................................................... 54
- 5.6 Harmonic series and Fourier analysis ................................. 55
- 5.7 The Doppler effect ................................................................. 57
- 5.8 Flux, intensity and luminance .............................................. 58
Single best answer questions .................................................. 59
Multiple choice questions ......................................................... 60

#### 6 Pressure measurement
- 6.1 Absolute and relative pressure ........................................... 61
- 6.2 Simple pressure-measuring devices .................................. 63
- 6.3 Pressure relief valves ............................................................ 68
- 6.4 Pressure regulator valves ...................................................... 69
- 6.5 The siphon effect and air entrainment ................................. 71
- 6.6 Blood pressure ................................................................. 73
- 6.7 Non-invasive blood pressure measurement ................... 74
- 6.8 Invasive blood pressure monitoring .................................. 76
Single best answer questions .................................................. 79
Multiple choice questions ......................................................... 80

#### 7 Humidity
- 7.1 Water vapour content of air ............................................. 81
- 7.2 Absolute and relative humidity ........................................... 82
- 7.3 Measuring humidity ............................................................ 83
- 7.4 Humidity and human physiology ....................................... 85
- 7.5 Humidification of inhaled air ............................................. 85
- 7.6 Nebulizers ................................................................. 88
Single best answer questions .................................................. 89
Multiple choice questions ......................................................... 90

#### 8 Measurement of gas flow
- 8.1 Flow .................................................................................. 91
- 8.2 Laminar flow ................................................................. 92
- 8.3 Turbulent flow .................................................................. 95
- 8.4 Bernoulli’s principle .......................................................... 98
- 8.5 The Venturi effect ............................................................. 100
- 8.6 The Coanda effect ............................................................. 101
- 8.7 Volume and flow measurement ..................................... 102
Single best answer questions .................................................. 107
Multiple choice questions ......................................................... 108
9 The gas laws........................................................................................................................................109
  9.1 The ideal gas ................................................................................................................................109
  9.2 Avogadro's law and Avogadro's constant .............................................................................109
  9.3 Partial pressure .........................................................................................................................112
  9.4 Boyle's law .................................................................................................................................115
  9.5 Charles's law ...............................................................................................................................117
  9.6 The pressure law: Gay-Lussac's law .................................................................................118
  9.7 The combined gas laws ...........................................................................................................120
  9.8 The universal gas law .............................................................................................................121
  Single best answer question ........................................................................................................123
  Multiple choice questions .............................................................................................................123

10 Diffusion, osmosis and solubility..........................................................................................125
  10.1 Diffusion ..................................................................................................................................125
  10.2 Diffusion of respiratory and anaesthetic gases ...............................................................127
  10.3 Lung function test of pulmonary diffusing capacity ......................................................129
  10.4 Osmosis ..................................................................................................................................130
  10.5 Solubility ..................................................................................................................................131
  10.6 Partition coefficient .............................................................................................................133
  10.7 Colligative properties of solutions .....................................................................................135
  Single best answer questions ........................................................................................................136
  Multiple choice questions .............................................................................................................137

11 Measuring gas and vapour concentrations .........................................................................138
  11.1 Respiratory gas monitoring ...............................................................................................138
  11.2 Infrared absorption spectroscopy for gases ....................................................................139
  11.3 Capnography .......................................................................................................................141
  11.4 Paramagnetic oxygen analysers .......................................................................................141
  11.5 Electrochemical cells ...........................................................................................................143
  11.6 Electrodes used in arterial blood gas analysis .................................................................145
  11.7 Other gas monitoring techniques .......................................................................................147
  Single best answer questions ........................................................................................................149
  Multiple choice questions .............................................................................................................149

12 Vaporizers ..................................................................................................................................150
  12.1 Introduction to vaporizers .................................................................................................150
  12.2 The draw-over vaporizer ....................................................................................................151
  12.3 Variable bypass vaporizers ...............................................................................................151
  12.4 Factors affecting delivered concentration of anaesthetic agent ....................................153
  12.5 Direct injection vaporizers ...............................................................................................155
  12.6 The dual circuit vaporizer: a vaporizer to deliver desflurane .........................................155
  12.7 Vaporizers functioning at altered atmospheric pressures ............................................156
  Single best answer questions ........................................................................................................157
  Multiple choice questions .............................................................................................................157
### 13 Medical gas supplies ................................................................. 158
- 13.1 General principles of compressed gas cylinders .................................................. 158
- 13.2 Gas that liquefies in a cylinder ............................................................................. 161
- 13.3 Piped medical gas ............................................................................................... 164
- 13.4 Vacuum and suction ............................................................................................ 166
- 13.5 Combustion risk ................................................................................................. 167
- Single best answer questions ........................................................................................ 169
- Multiple choice questions .......................................................................................... 169

### 14 Breathing systems and ventilation .................................................. 170
- 14.1 Key components in breathing systems ................................................................. 170
- 14.2 The circle system ............................................................................................... 171
- 14.3 The Mapleson classification ................................................................................ 173
- 14.4 Mapleson A, B and C systems ............................................................................. 174
- 14.5 Mapleson D, E and F systems ............................................................................. 176
- 14.6 Minimizing pollutants in the theatre environment ............................................. 178
- 14.7 Ventilators ........................................................................................................... 179
- 14.8 Ventilator designs ............................................................................................... 181
- 14.9 Modes of ventilation ........................................................................................... 182
- 14.10 Non-invasive ventilation ................................................................................... 184
- Single best answer questions ........................................................................................ 185
- Multiple choice questions .......................................................................................... 186

### 15 Optics ................................................................................................. 187
- 15.1 Refraction ............................................................................................................ 187
- 15.2 Optical fibres ...................................................................................................... 189
- 15.3 Fibreoptic endoscopes ....................................................................................... 191
- 15.4 Absorption of light: Beer’s law .......................................................................... 192
- 15.5 Haemoglobin absorption spectra ....................................................................... 193
- 15.6 Pulse oximetry ................................................................................................... 194
- 15.7 Trans-cranial near-infrared spectroscopy ......................................................... 195
- 15.8 CO-oximetry ....................................................................................................... 196
- Single best answer questions ........................................................................................ 197
- Multiple choice questions .......................................................................................... 197

### 16 Blood flow measurement ...................................................................... 198
- 16.1 Measurement of liquid flow ................................................................................ 198
- 16.2 Dye dilution and washout curves ....................................................................... 198
- 16.3 Thermodilution – pulmonary artery catheter ...................................................... 202
- 16.4 Lithium chloride dilution .................................................................................... 204
- 16.5 Doppler velocity and flow measurement ............................................................... 204
- Single best answer questions ........................................................................................ 208
- Multiple choice questions .......................................................................................... 209
17 Equipment management ................................................................. 210
   17.1 Equipment management principles ........................................ 210
   17.2 Safety critical systems .......................................................... 212
   17.3 Calibration .......................................................................... 213
   17.4 Cleaning and disinfection ..................................................... 214
   17.5 Sterilization ....................................................................... 216
   Single best answer questions ...................................................... 217
   Multiple choice questions ......................................................... 218

18 Basics of electricity ................................................................. 219
   18.1 Electric current .................................................................. 219
   18.2 Electric potential ............................................................... 220
   18.3 Electrical resistance ........................................................... 221
   18.4 Rules of electrical circuits .................................................. 223
   18.5 Electrical power and energy ............................................... 224
   18.6 Resistor combinations ....................................................... 225
   18.7 Measuring small physiological changes: the Wheatstone bridge 227
   Single best answer questions ...................................................... 228
   Multiple choice questions ......................................................... 229

19 Electromagnetism and alternating current ............................... 230
   19.1 Magnetic fields ................................................................. 230
   19.2 Electromagnetism .............................................................. 232
   19.3 Alternating current and power .......................................... 233
   19.4 Transformers ................................................................... 235
   19.5 High voltage power transmission ..................................... 236
   Single best answer questions ...................................................... 239
   Multiple choice questions ......................................................... 240

20 Electrical shocks and safety ..................................................... 241
   20.1 Electrocution ..................................................................... 241
   20.2 Earthing .......................................................................... 243
   20.3 Electrical safety devices .................................................... 245
   20.4 Micro-shock ..................................................................... 246
   20.5 Electrical safety standards ............................................... 247
   20.6 Static electricity ............................................................... 248
   20.7 Current density and electro-surgery ................................... 248
   Single best answer questions ...................................................... 252
   Multiple choice questions ......................................................... 252

21 Electrocardiography, pacing and defibrillation ...................... 253
   21.1 Capacitance ..................................................................... 253
   21.2 Defibrillators .................................................................... 255
   21.3 Biological potentials ......................................................... 258
21.4 Electrocardiography ................................................................. 259
21.5 Potentials in skeletal muscle: electromyography .................. 262
21.6 Potentials in the brain: electroencephalogram ..................... 262
21.7 Cardiac pacemakers ................................................................ 264
Single best answer questions .................................................... 267
Multiple choice questions ......................................................... 268

22 Processing, storage and display .............................................. 269
22.1 The ‘black box’ ........................................................................ 269
22.2 Transducers and signal pick-up ............................................. 270
22.3 Signal conditioning ................................................................. 271
22.4 Analogue-to-digital conversion ............................................ 273
22.5 Hardware, software and operating systems .......................... 274
22.6 Displays ................................................................................... 275
22.7 Networking ............................................................................. 276
Single best answer questions .................................................... 277
Multiple choice questions ......................................................... 277

23 Ultrasound .................................................................................. 278
23.1 Ultrasound waves ................................................................. 278
23.2 Imaging modes ...................................................................... 280
23.3 Attenuation ........................................................................... 281
23.4 Reflection and acoustic impedance ...................................... 283
23.5 Resolution ............................................................................. 285
23.6 Cardiac ultrasound: TOE and TTE ....................................... 286
23.7 Therapeutic ultrasound ....................................................... 287
Single best answer questions .................................................... 288
Multiple choice questions ......................................................... 289

24 Lasers .......................................................................................... 290
24.1 The principle of the laser ...................................................... 290
24.2 Types of medical laser ......................................................... 293
24.3 Precautions with laser treatment ....................................... 294
Single best answer questions .................................................... 296
Multiple choice questions ......................................................... 297

25 Magnetic resonance imaging .................................................. 298
25.1 Principles of magnetic resonance imaging .......................... 298
25.2 Safety considerations .......................................................... 302
Single best answer questions .................................................... 304
Multiple choice questions ......................................................... 305

26 Nuclear physics and radiation ............................................... 306
26.1 Radioactivity ......................................................................... 306
26.2 Radiation .............................................................................. 307
26.3 Radioactive decay and half-life ......................................... 308
26.4 Ionizing radiation ............................................................... 309
26.5 Radiotherapy ................................................................. 310
26.6 X-rays: transmission, production and imaging .................. 310
26.7 Scintigraphy and SPECT scans .................................... 312
26.8 Positron emission tomography .................................... 313
26.9 X-ray computed tomography ...................................... 314
Single best answer questions .................................................. 315
Multiple choice questions ....................................................... 316

27 Basic mathematical concepts .................................................. 317
27.1 Basics ................................................................................. 317
27.2 Very large and very small numbers .................................... 318
27.3 Functions ............................................................................. 320
27.4 Trigonometry ................................................................. 322
27.5 Calculus ............................................................................. 324
27.6 Exponential growth .......................................................... 327
27.7 Exponential decay ............................................................. 329
Multiple choice questions ....................................................... 331

28 Physical quantities and SI units ................................................. 332
28.1 Physical constants .......................................................... 332
28.2 Fundamental and derived SI units .................................... 332
28.3 Standard prefixes for SI units ........................................... 334
28.4 Respiratory and gas quantities ........................................... 334
Multiple choice questions ....................................................... 337

29 Statistics ............................................................................. 338
29.1 Errors, uncertainty and averages ....................................... 338
29.2 Study design ................................................................. 339
29.3 Outcome measures and the uncertainty of their definition ..... 340
29.4 The basis of meta-analysis and evidence-based medicine (EBM) ............................................. 341
29.5 Types of data and their representation ................................ 341
29.6 Parametric and non-parametric distributions .................... 343
29.7 Indices of central tendency and variability ......................... 345
29.8 Common statistical tests .................................................. 348
Answers to self-assessment questions ......................................... 353
Index ....................................................................................... 357
Chapter 4
Temperature and heat

Having read this chapter you will be able to:
• Understand the concept of heat and thermal energy.
• Explain temperature and understand temperature scales.
• Understand heat transfer through conduction, convection and radiation.
• Appreciate the significance of the laws of thermodynamics.
• Appreciate the adiabatic model relevant to a discharging cylinder of gas and associated cooling.

4.1 Heat

A lit match reaches a temperature fierce enough to burn skin, but the heat it generates could not warm a cup of water. In contrast, the water in a radiator can warm a room even though it is at a significantly lower temperature - the radiator can transfer far more heat than the hotter match. Temperature is a measure of how hot or cold an object is. Above absolute zero, a body’s atoms or molecules are in constant motion and the amplitude of their vibrations determines the temperature of the body. Adding heat to a body raises its temperature. Heat is the thermal energy that flows from one body in contact with another when they are at differing temperatures.

Heat capacity

Although not immediately obvious, a bucket of water at room temperature contains more thermal energy than a red-hot nail. This is because the water has a much larger mass, and thus a larger heat capacity than the nail so it can store more energy without raising its temperature considerably.

If the nail is quenched in the water in the bucket there will be a small rise in temperature, but this will be much smaller than the drop in temperature of the nail. The material of the nail (iron) and the water can also be defined in terms of a quantity called the specific heat capacity, which is the heat capacity per unit mass. Iron has a value of 0.450 J·g⁻¹·K⁻¹, compared to a much greater 4.18 J·g⁻¹·K⁻¹ for water, meaning that the nail could be quenched effectively by a fairly small amount of water. The amount of heat \( Q \) needed to raise the temperature of a body is given by the following equation:

\[
Q = m \cdot c \cdot \Delta T
\]

where
- \( \Delta T \) is the temperature change
- \( c \) is the specific heat capacity
- \( m \) is the mass of the body
Units. Thermal energy is another form of energy so is expressed in joules, J (or kg·m²·s⁻²). In some countries, the calorie is used as a unit of thermal energy, where 1 calorie = 4.18 J. One calorie is defined as the energy required to raise the temperature of 1 gram of water from 15°C to 16°C. Specific heat capacity is normally expressed in units of J·g⁻¹·K⁻¹.

Clinical examples

Respiratory heat loss
The heat lost by the body through respiration may be categorized as roughly 25% through warming of surrounding air, and 75% through humidification of air.

Shivering generates heat
Shivering raises the metabolic rate from a resting power of 80 W to around 320 W, a fourfold increase. The majority of this power is converted into heat (through the inefficiency of the muscles), warming the body.

4.2 Temperature

The more a substance is heated, the more kinetic energy the molecules gain. Temperature quantifies the average kinetic energy of the atoms or molecules, i.e. how fast they are moving around. As a substance is heated, its atoms or molecules move faster. In solids, the atoms vibrate more vigorously; for example, atoms in a crystal lattice vibrate around their average position dictated by their lattice bonds. In a gas or liquid, the atoms or molecules move faster and bump into each other more energetically. At any temperature, these tiny particles have a wide range of kinetic energies and the temperature represents the average kinetic energy. Even at low temperatures, a small proportion are moving or vibrating very fast.

Temperature scales

Temperature scales are based on known, repeatable temperature points of reference. The Celsius scale uses the boiling and freezing points of pure water at atmospheric pressure. Zero on the Fahrenheit scale was set at the lowest freezing point obtainable with an ice–water–salt mixture. The freezing point of water is 32°F and the boiling point is 212°F, being 180 degrees apart. Figure 4.1 shows the kelvin, Celsius and Fahrenheit temperature scales.

Temperature sensors don’t measure temperature directly, but instead measure a change in a physical property sensitive to temperature. For example, a simple thermometer relies on expansion of a liquid, such as mercury, inside a glass tube. Modern thermometers use an electrical device such as a thermocouple and display the temperature on a digital read-out.

Absolute zero

The theoretical temperature of absolute zero is the starting point of the kelvin scale. At 0 K, absolute zero, molecules contain no kinetic energy. Though attempts to reach absolute zero have come very, very close, true absolute zero can never be reached.
Figure 4.1. Temperature scales: kelvin, Celsius and Fahrenheit.

**Worked example**

**Question**
Does a temperature rise from 50°C to 100°C represent a doubling of the absolute temperature?

**Answer**
No. Temperature starts at –273°C (0 kelvin) where the body holds no thermal energy. Zero on the Celsius scale is simply the freezing point of water at sea level (1 atmosphere). So an increase of 50°C is actually only an 18% increase in absolute temperature.

**Body temperature**

Humans, like all mammals and birds, are **homeothermic**; that is, they control their core body temperature within a narrow range. For humans this is 36.8 ± 0.4°C, although this depends on the level of activity. Temperature also varies by around 0.4°C during normal circadian rhythm, being lowest in the early hours of the morning and highest in the evening. The mean temperature of the body’s central core is steady, while the forehead skin temperature ranges from 29 to 33°C.

**4.3 Transfer of heat**

Consider a hot cup of coffee left on a table overnight. The next morning the coffee is at room temperature because heat flows from the hot coffee to the surroundings. In the presence of a temperature gradient, heat flows from hot to cold until thermal equilibrium is reached. The coffee, the table and the room air all settle at the same temperature. Heat transfer from one body to another can occur by three main methods: conduction, convection and radiation.
4.3 Transfer of heat

**Conduction**

Holding metal or wooden objects on a winter’s day are very different sensations. Metal feels notably colder, yet both objects are in the same environment so are at the same temperature. The hand is at a higher temperature (than the metal or wood), so heat is conducted from the skin due to the temperature difference. The heat is conducted at a much faster rate to the metal because metal is a far better conductor of heat than wood.

Conduction is the process of kinetic energy in the form of heat being transferred from one body to another. In other words, it is the direct transfer of heat energy from molecule to molecule. Some materials, such as metals, are very good at conducting heat, whereas plastics are generally not and are therefore described as good insulators. Conduction cannot occur in a vacuum, as it is an exchange of thermal energy between bodies. Gases are poor conductors; for example, copper is an incredible 16 000 times better at conducting heat than air; this means that the heat loss during breathing is low.

**Units.** The units of conductivity are W·K⁻¹·m⁻¹.

---

**Worked example**

**Question**

Why does a string vest still offer a degree of warmth to the wearer?

**Answer**

Static air is held amongst the holes in the vest. Gases in general are poor conductors of heat and air is typical of this. Similarly, hospital blankets are often of a knitted design with many holes to take advantage of this principle.

---

**Convection**

Once on the operating table, if not appropriately covered, patients cool down very quickly due to convection. Heat is transferred due to the temperature gradient between the patient and the cooler air immediately surrounding the patient. This warmed air is then moved by the operating theatre’s laminar flow system and is replaced by colder air, once again establishing a temperature gradient through which heat is lost.

The heat loss from breathing involves convection. For ventilated patients or patients with supplemental oxygen the dry air/oxygen from cylinders means that energy is lost in humidifying inhaled air. Like conduction, convection cannot exist in a vacuum, as it needs a medium through which the thermal energy can be transported. Convection can be a passive or an active process:

- **passive convection** can be seen in a hot object cooling in still air (note that some heat loss also occurs by radiation and conduction)
- **active convection** can be achieved by blowing cool air over the object with a fan.

---

**Definition**

**Conduction:** The flow of heat by conduction occurs via direct collisions between the atoms and molecules of warmer and cooler regions and the resultant transfer of kinetic energy. Conduction can occur in solids, liquid and gases.

**Convection:** The transfer of heat from a body by the liquid or gas which surrounds it. The fluid has a tendency to rise if it is hotter because it is less dense; colder, denser material sinks under the influence of gravity.
Chapter 4  Temperature and heat

Radiation of heat

When the sun emerges from behind a cloud its warmth is immediately apparent, despite the fact that the heat has travelled from over 93 million miles away! Neither convection nor conduction can adequately explain how this heat is transferred, because both rely on a medium to carry the heat and yet space is virtually a vacuum with very few molecules present. The answer lies in radiant heat: the sun's heat is carried by electromagnetic waves (see Chapter 5), most of which are invisible to the naked eye. When electromagnetic waves are being discussed in terms of the energy they are carrying they are often referred to as electromagnetic radiation.

The phenomenon of thermal radiation is not limited to the sun: imagine two objects, one hot and one cold, placed in a vacuum with no physical contact between them. Heat transfer via either conduction or convection is impossible because in the vacuum there is no transporting medium, yet the two objects will eventually reach a common temperature. The heat transfer occurs because both objects continually release and absorb energy in the form of electromagnetic radiation: the emitted energy is commonly called thermal radiation: it can also be referred to as radiant heat.

4.4 Black-body radiation

A black body is a body that absorbs all radiation that falls upon it. It follows that dark-coloured objects are the best absorbers, as shown in Figure 4.2. Black bodies are also the best emitters. Painting a radiator matt black increases its efficiency at heating a room.

The amount of radiation emitted by a black body depends on its temperature, and is described by the Stefan–Boltzmann law. This law states that the emitted power is equal to the fourth power of the absolute temperature (the temperature relative to absolute zero).

\[ P = e \cdot \sigma A T^4 \]

where  
- \( P \) is the radiated power  
- \( T \) is the temperature  
- \( A \) is the surface area  
- \( \sigma \) is the Stefan constant (\( = 5.67 \times 10^{-8} \text{ J m}^{-2} \text{s}^{-1} \text{K}^{-4} \))  
- \( e \) is the emissivity

Clinical example

Warming and cooling blankets

Controlling patient temperature is most commonly achieved with the aid of a warming blanket where a fan drives hot air through an inflatable blanket. This method of convection has also been adapted to cool patients following a cerebral insult, with the hope that a reduced metabolic rate will reduce oxygen demand and minimize ischaemic insult. Instead of air, hyper-hypothermia water therapy systems can be employed. The water is pumped through a collection of garments such as a head wrap, patient vest and lower body blanket.

Definition

**Radiation**: hot bodies emit thermal energy in the form of electromagnetic radiation; this radiation is absorbed by the surroundings, resulting in heat transfer.

**Stefan–Boltzmann law**: the radiation energy per unit time from a black body is proportional to the fourth power of the temperature.
The radiant power is also proportional to the emissivity, a dimensionless quantity (i.e. it has no units), which quantifies the ability of a body to radiate heat; this is established by a comparison to a perfect black body surface at the same temperature. The emissivity of a black body is 1, while true bodies have a value of less than 1.

The wavelength of the emitted radiation also depends on the temperature. At room temperature, or body temperature, a body will emit electromagnetic radiation over a range of wavelengths within the infrared region of the electromagnetic spectrum. At higher temperatures, the body will emit a shorter wavelength radiation, as shown in Figure 4.3, until at very high temperatures (greater than 800 K), the object begins to glow red-hot as electromagnetic radiation in the visible region is emitted (the visible region spans the wavelength range from approximately 380 to 700 nanometres). At higher temperatures still, the object glows orange, yellow and eventually white as shorter and shorter wavelengths of radiation are emitted. The sun’s surface is at a temperature of approximately 5000 K, so although a wide range of wavelengths are emitted, it appears bright white to the eye. Astronomers observe the black-body radiation spectrum of distant stars and from this it is possible to calculate the stars’ surface temperature and energy output.

**Clinical example**

**Thermogram scans**
A thermogram records the temperatures of a subject. Breast thermography is a non-invasive screening procedure that detects and records temperatures from predominantly infrared heat emissions. Metabolic and vascular activity in pre-cancerous tissue, and also the area surrounding developing breast cancer, is often high. Different colours are used to represent the temperature zones.
Chapter 4  Temperature and heat

4.5 Regulation of body temperature

Mammals and other warm-blooded animals continuously produce heat and this is evident by the rapid cooling that follows death. An average healthy male at rest emits approximately 50 watts per square metre of body surface, or approximately 80 watts. The rate of thermal emission is affected by the basal metabolic rate (BMR), which increases after eating and during exercise, leading to an increase in the core temperature of the body. In cold ambient conditions, increased heat production can also be achieved by shivering and through voluntary muscular activity. There is no direct mechanism for a reduction in heat production to compensate for overheating; instead the body relies on cooling mechanisms such as sweating.

There are several routes of heat loss from the body, summarized in Table 4.1. Clearly the statement that 90% of body heat is lost through the head is nonsense; the actual figure is probably somewhere between 20 and 40%.

Table 4.1. Routes of heat loss from the body.

<table>
<thead>
<tr>
<th>Heat loss</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td>40%</td>
</tr>
<tr>
<td>Convection</td>
<td>30%</td>
</tr>
<tr>
<td>Evaporation of skin moisture</td>
<td>20%</td>
</tr>
<tr>
<td>(sweating)</td>
<td></td>
</tr>
<tr>
<td>Respiration</td>
<td>10%</td>
</tr>
</tbody>
</table>
4.6 Measuring temperature

Thermometric properties

All thermometers work by exploiting a particular physical, or thermometric property that changes with temperature in a predictable fashion. A simple relationship between temperature and the variable allows for easy measurement. Table 4.2 lists the most commonly used thermometric properties. Ideally the property that changes with temperature should be linearly proportional to temperature; for example, the length of a liquid column in a liquid-in-glass thermometer. Many thermometers, however, utilize non-linear thermometric properties; for example, a thermistor.

**The liquid-in-glass thermometer**

The liquid-in-glass thermometer (Figure 4.4) is used to measure temperatures in the oral, axillary and rectal regions. The liquid expands linearly as the temperature rises, but the expansion is only 1–2% of the total volume so the glass casing of the column is designed to magnify the narrow liquid column. Originally filled with mercury, thermometers are now filled with an alcohol-based liquid. There is a constriction between the bulb and the column and this allows the thermometer to be
removed from the patient and read at leisure; the thermometer has to be shaken to return the liquid to the bulb. Though not particularly sensitive, liquid-in-glass thermometers have the advantage of simplicity and low cost. They are limited by their fragility and slow response time.

**Bourdon thermometer**

The Bourdon thermometer is popular in industry because it is capable of measuring high temperatures accurately. It is based on the principle described in Charles’s law: as the temperature of a gas increases, the pressure proportionately increases with it (see Chapter 9). The gas is held in a reservoir or bulb and is linked by a capillary tube to a hollow Bourdon tube. As the temperature increases the gas expands, the pressure increases and the Bourdon tube uncoils – this is linked to a pointer behind which is a temperature on a calibrated dial. The Bourdon thermometer is similar to the Bourdon pressure gauge (see Chapter 6) because they both measure the expansion of a fluid. The filling for the bulb of the Bourdon thermometer can be either liquid or gas, because they both expand as temperature increases.

<table>
<thead>
<tr>
<th>Thermometer</th>
<th>Thermometric property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid-in-glass</td>
<td>Expansion of a liquid</td>
</tr>
<tr>
<td>Bimetallic strip</td>
<td>Expansion of solid</td>
</tr>
<tr>
<td>Bourdon</td>
<td>Pressure change of gas</td>
</tr>
<tr>
<td>Resistance</td>
<td>Resistance of coil of wire</td>
</tr>
<tr>
<td>Thermistor</td>
<td>Resistance of metal oxides</td>
</tr>
<tr>
<td>Thermocouple</td>
<td>Seebeck effect</td>
</tr>
<tr>
<td>Infrared</td>
<td>Thermal radiation</td>
</tr>
</tbody>
</table>

Figure 4.4. A liquid-in-glass thermometer.
Electronic thermometers

Modern medical thermometers are usually electronic, and are either of the handheld type, or are part of an integrated patient monitoring system. Electronic thermometers normally utilize either a temperature-dependent resistor or a simple temperature sensing device called a thermocouple. Electronic thermometers are now relatively cheap, have highly sensitive sensors and can be calibrated accurately. They also have the advantage that they are easy to read and can be logged automatically, a useful feature for long-term patient monitoring.

Platinum resistance thermometers

This is the simplest type of electronic thermometer. The resistance of a thin platinum wire has a linear relationship with temperature, as shown in Figure 4.5. The device measures resistance and this is then converted to temperature using a simple calibration equation. This type of thermometer has the disadvantage that it is not sensitive compared to a thermistor (see below).

Thermistors

A thermistor is a temperature-sensitive resistor whose resistance changes with temperature. Most temperature-sensitive resistors are constructed from a semiconductor material (carefully chosen metal oxides) and the resistance increases with a fall in temperature (they have a negative temperature coefficient) and they are known as negative thermal conductivity (NTC) thermistors. A Wheatstone bridge circuit (see Chapter 18) is used to measure the resistance accurately.

The main disadvantage of thermistors is the non-linear resistance versus temperature characteristic, although this can be compensated for using an appropriate calibration equation programmed into an electronic measurement system. Thermistors remain highly popular due to their cost, miniature size and convenience. Thermistor probes are commonly placed in the nasopharynx, oesophagus, rectum or bladder (integrated with a urinary catheter). They have excellent accuracy and their small mass means that there is a quick response to variations in temperature.

![Figure 4.5. Resistance versus temperature: the steeper gradient of the thermistor as opposed to platinum wire means it is more sensitive to variations in temperature.](image-url)
Thermocouples rely on the Seebeck effect: when a junction is formed between two dissimilar metals a small voltage is produced across the junction and this voltage varies with temperature.

Temperature-measuring thermocouples are traditionally constructed with two junctions, as shown in Figure 4.6. One junction is used as the measurement probe while the other (the ‘reference’ junction) is held at a fixed, known temperature, for example, melting ice at 0°C. The most common thermocouples are made from copper and constantan (an alloy of copper with 40% nickel). The voltage across the thermocouple is known as Seebeck voltage, given by:

\[ V = \alpha (T_1 - T_2) \]

where \( \alpha \) is the Seebeck coefficient (V · K\(^{-1}\)),
\( T_1 \) and \( T_2 \) are the temperatures at the two end junctions,
\( V \) is the voltage generated.

The Seebeck coefficient is a constant that depends on the two metals used. Modern thermocouple-based thermometers use a single junction, making the reference junction redundant, instead using a special circuit called a cold-junction compensator. This circuit contains a thermistor, which senses the ambient temperature, and thus compensates the output of the thermocouple for any temperature. Thermocouples can be made extremely small and as a result have very low heat capacity. They therefore respond rapidly and can be used to measure the temperature of very small volumes of matter. Thermocouples can also produce very accurate readings if correctly calibrated.

Infrared tympanic thermometers

A tympanic thermometer measures the temperature in the middle ear by detecting the radiation emitted by the eardrum. The sensor in this type of thermometer is a thermopile, an electronic device which converts thermal energy into electrical energy. Infrared radiation emitted from the eardrum causes a temperature rise in the thermopile and, as explained in Section 4.4, the radiated power of the infrared energy provides an indication of the emitter temperature. The tympanic membrane is a

Figure 4.6. A thermocouple, where A and B are different metals.
suitable site because its blood supply is similar in temperature and location to the blood supplying
the hypothalamus, the site of the body’s thermoregulatory centre and, therefore, an ideal location for
core temperature estimation.

Tympanic thermometers can give falsely low temperature readings depending on the anatomy of
the ear, the build-up of earwax or other debris, or poor user technique. The most accurate readings
are obtained if the user lifts the ear upwards, giving the instrument a clear line of sight to the tympanic
membrane, as shown in Figure 4.7. Otherwise it responds to infrared rays from the ear canal that are
approximately 2°C lower than the tympanic membrane, giving a falsely low reading. This type of
thermometer is obviously limited by the fact it can only be used in one area of the body to sample
temperature.

4.7 Laws of thermodynamics

Thermodynamics deals with the transfer of heat energy to other
forms of energy, most notably mechanical work. The temperature,
pressure and volume of a gas are all related to their thermal energy.
Study of the laws of thermodynamics allows an understanding of
these relationships and from this, predictions about a wide range
of physical processes can be made.

**First law of thermodynamics**

Imagine an enclosed chamber that has absolutely no commu-
nication with the outside world: it is perfectly insulated. Can
the total energy inside that chamber ever change? The first law
of thermodynamics categorically says no: the only change of
energy can come about by energy being added or subtracted externally.

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**Definition**

**Thermodynamics**: the branch of physics that deals with the interaction between heat (thermal energy) and other forms of energy.

**Definition**

**First law of thermodynamics**: the change in internal energy of a system is equal to the heat added minus the work done by the system.
In essence it is a law about the conservation of energy: although energy assumes many forms, the total quantity of energy is constant, and when energy disappears in one form it appears simultaneously in other forms. Put simply, energy can neither be created nor destroyed. An equation accompanies this law that can be considered the bookkeeping of energy states:

$$\Delta U = Q \pm W$$

where:  
$\Delta U$ is the change in the total energy of the system  
$Q$ is heat added to the system  
$W$ is work done by the system

By convention if energy leaves the system the change in energy is classed as positive, but negative if energy is gained by the system.

**Clinical example**

*The human body*

The first law of thermodynamics can be considered as another way of writing the conservation of energy.

$$\Delta U \text{ (stored energy)} = Q \text{ (heat loss/gain)} – W \text{ (work done)}$$

where:  
$\Delta U$ is the stored energy in the form of food, fat and heat  
$Q$ is the heat loss from or gain to the body (e.g. heat lost swimming in cold sea (-ve) or heat gained in a hot sauna (+ve))  
$W$ is the work done, such as when climbing a flight of stairs

### Second law of thermodynamics

Heat cannot pass naturally from a colder body to a hotter one; work is required, which is why a fridge requires energy. Work is done to pump heat from the fridge’s interior to the external environment.

$$\Delta S = \frac{\Delta Q}{T}$$

where:  
$\Delta S$ is the change in entropy  
$\Delta Q$ is the heat entering the system  
$T$ is the temperature

**Units.** Entropy does not have units – it is a measure of disorder. The most probable state of a system is the state with the largest entropy.

### Third law of thermodynamics

**Definition**

*Third law of thermodynamics: the temperature absolute zero is unattainable.*

As a system approaches absolute zero, all processes cease and the entropy (a measure of disorder) of the system approaches a minimum value. It is impossible by any procedure, no matter how idealized, to reduce any system to the absolute zero of temperature (0 K) in a finite number of operations.
**Units.** The Kelvin scale has absolute zero as the lowest temperature theoretically possible. However, the third law states that it can never be quite reached!

In other words..., scientist, politician and author C.P. Snow put the three laws in a more memorable way:

1. You cannot win (that is, you cannot get something for nothing, because matter and energy are conserved).
2. You cannot break even (you cannot return to the same energy state, because there is always an increase in disorder; entropy always increases).
3. You cannot get out of the game (because absolute zero is unattainable).

**Heat lost by gas expansion**

When a gas expands it does work. **Adiabatic expansion** simply refers to a process that involves no external heat transfer, so any work done by an adiabatic system is at the expense of the system’s existing internal energy. In other words, an adiabatic system can be considered entirely insulated.

For a process of gas expansion that is adiabatic, there is no change in the system’s total energy, so $\Delta U = 0$ and Equation 4.4 becomes:

$$0 = Q \pm W$$

for an adiabatic process

**Joule–Thomson effect**

After enthusiastically pumping up a bike tyre, the valve of the pump feels hot to the touch. Work is done to compress the gas into the tyre so the temperature of the gas rises. If the tyre is pumped more slowly the valve would not heat up, as the heat would have dissipated to the surroundings. The enthusiastic cyclist temporarily creates an adiabatic process because minimal heat had time to enter or leave the system (the system being the enclosed pump, valve and tyre).

The temperature rises when a gas is compressed. Conversely, when gas expands its temperature drops. As a medical gas cylinder empties there is a drop in temperature in the gas expelled and there is a danger that the valve will be obstructed by ice as the gas cools on exit from the cylinder - this is why gases are stored as dry gases. This principle is utilized by a **cryoprobe**, which is cooled by rapid expansion of compressed gas.

If gas in the clinical setting rapidly undergoes compression its temperature will rise. So if the gases in the piping of the anaesthetic machine are compressed from atmospheric pressure to cylinder pressure there is a resultant rise in temperature.

**Summary**

- Heat is the amount of thermal energy contained by an object.
- The specific heat capacity of a substance determines how much heat is required to raise its temperature.
- Heat flows from a region of high temperature to a region of lower temperature by conduction.
- Thermal energy can travel though a vacuum by the process of radiation.
• Thermometers rely on thermometric properties, that is, properties which change with temperature.
• Thermistors and thermocouples are sensitive temperature-sensing devices commonly used in electronic medical thermometers.
• Thermocouples rely on the Seebeck effect, where a voltage is produced across a two-junction thermocouple if each junction is at a different temperature.

Single best answer questions

For each of these questions, only one option is correct.

1. Thermistors are better temperature sensors than platinum wires because they:
   (a) have a more linear response
   (b) have a positive temperature coefficient of resistance
   (c) are more sensitive
   (d) give better repeatability
   (e) are cheaper

2. The body loses heat by which processes and by what proportion?
   (a) Convection 40%; radiation 30%; evaporation and respiration 20%
   (b) Convection 40%; radiation 40%; evaporation and respiration 20%
   (c) Convection 30%; radiation 40%; evaporation and respiration 30%
   (d) Convection 30%; radiation 30%; evaporation and respiration 40%
   (e) Convection 20%; radiation 40%; evaporation and respiration 40%

3. The total radiated power of an object is proportional to the objects:
   (a) temperature
   (b) temperature-squared
   (c) emittance
   (d) surface area
   (e) mass

4. The temperature of the human body on the Kelvin scale is:
   (a) 37 K
   (b) 298.15 K
   (c) 300 K
   (d) 310 K
   (e) 335 K

5. An infrared tympanic thermometer:
   (a) must be in good thermal contact with the ear canal
   (b) must have a clear line of sight to the tympanic membrane
   (c) requires several seconds to obtain a reading
   (d) is insensitive to debris in the ear
   (e) may be used in other measurement sites
Multiple choice questions

For each of these questions, more than one option may be correct.

1. Which of the following statements are true of thermistors?
   (a) They have a rapid response time.
   (b) They are not suitable for internal use due to harmful metal content.
   (c) They are small.
   (d) Readings can be taken continuously.
   (e) Expense prohibits manufacture as disposable items.

2. If two bodies are in thermal equilibrium:
   (a) they have the same temperature
   (b) they contain the same quantity of heat
   (c) they have the same heat capacity
   (d) no heat flows between them
   (e) they have the same specific heat capacity

3. A body of emissivity 0.8 compared to a body of emissivity 0.4:
   (a) is a better emitter and a less good absorber of thermal radiation
   (b) is a better emitter and a better absorber of thermal radiation
   (c) is a better emitter but the absorptive abilities are not known
   (d) is more likely to be visibly lighter
   (e) is more likely to be visibly darker

4. 1 kg of iron at 25°C contains more heat than 100 mL of water at 50°C because:
   (a) the iron has a higher heat capacity than the water
   (b) iron has a higher specific heat capacity than water
   (c) the iron has a higher mass than the water
   (d) the iron atoms have a higher mean kinetic energy than the water molecules
   (e) iron has a higher density than water

5. On a cold day, metal feels colder to the touch than wood because:
   (a) metal has a higher specific heat capacity than wood
   (b) the metal is at a lower temperature than the wood
   (c) the metal is a better thermal conductor than wood
   (d) the metal has a lower specific heat capacity than the wood
   (e) the metal contains less heat than the wood