Energy enters an animal's body as chemical energy...

Chemical energy in body tissues becomes ingested energy for other organisms at death

Absorbed chemical energy

Biosynthesis

Inefficiency

Maintenance

Degradation of internal work

Inefficiency

Generation of external work

Chemical energy in exported organic matter

...and leaves as heat, chemical energy, or external work.

Mechanical energy of external work

Absorbed chemical energy is used to perform three major types of physiological work.

Ingested chemical energy

Environment

Animal

Growth

Chemical energy accumulated in body tissues
Lavoisier surrounded the animal with an ice-filled jacket.

An outer ice-filled jacket intercepted environmental heat.

Ice melted by animal heat yielded liquid water, which dripped out of the apparatus for collection and measurement.

Carefully measured airflow

Pure O₂

Animal chamber

Screen platform

CO₂ absorbent

Manometer

Inert object that occupies a volume equal to the volume occupied by the insect and the CO₂ absorbent in the animal chamber.
<table>
<thead>
<tr>
<th>Food</th>
<th>(a) kcal g(^{-1})</th>
<th>(b) kcal liter O(_2) g(^{-1})</th>
<th>(c) kcal per liter O(_2)</th>
<th>(d) RQ = (\frac{CO_2 \text{ formed}}{O_2 \text{ used}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate</td>
<td>4.2</td>
<td>0.84</td>
<td>5.0</td>
<td>(20.9)</td>
</tr>
<tr>
<td>Fat</td>
<td>9.4</td>
<td>2.0</td>
<td>4.7</td>
<td>(19.7)</td>
</tr>
<tr>
<td>Protein (urea)</td>
<td>4.3</td>
<td>0.96</td>
<td>4.5</td>
<td>(18.8)</td>
</tr>
<tr>
<td>Protein (uric acid)</td>
<td>4.25</td>
<td>0.97</td>
<td>4.4</td>
<td>(18.4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Foodstuff</th>
<th>Heat produced per unit O(_2) consumed (J/mL O(_2))</th>
<th>Heat produced per unit CO(_2) produced (J/mL CO(_2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates</td>
<td>21.1</td>
<td>21.1</td>
</tr>
<tr>
<td>Lipids</td>
<td>19.8</td>
<td>27.9</td>
</tr>
<tr>
<td>Proteins(^a)</td>
<td>18.7</td>
<td>23.3</td>
</tr>
</tbody>
</table>
(a) Extracellular compartment

Formation of ice crystals are stimulated by nucleating agent.
Solutes excluded from forming ice; solute concentration increases.

Intracellular compartment

Osmotic loss of water increases solute concentration, preventing ice crystals from forming.

T < 0°C

H₂O

(b) T << 0°C

Eventually, intracellular organelles are destroyed by excessive solute concentration.

H₂O

(b) Plasma antifreeze concentration

Plasma freezing point

Time of year

Sept Oct Nov Dec Jan Feb Mar Apr May June July Aug
The effect of temperature on membrane-lipid fluidity in six vertebrate species.

Fluidity is kept relatively constant at the respective ordinary body temperatures of the species by the evolution of different membrane phospholipid compositions.
Lizards acclimated to the cooler ambient temperature have a higher average metabolic rate at any given body temperature...

...than those acclimated to the warmer ambient temperature.

The chronic-response line has a lower slope than any of the three acute-response lines.

(a) Actual acclimation response, showing partial compensation

(b) Theoretical acclimation response, showing full compensation

In full compensation, after a drop in body temperature, the metabolic rate returns during acclimation to its original level.

In partial compensation, after a drop in body temperature, the metabolic rate rises during acclimation but does not return to its original level.
Effect of acclimation on O₂ consumption in frogs. Frogs acclimated to 5°C show a lower O₂ consumption compared to those acclimated to 25°C.

The graph on the right illustrates the calculation of Q₁₀, which is the ratio of metabolic rates at two different temperatures.

**Q₁₀**

\[ Q_{10} = \frac{193}{89} = 2.2 \]

\[ Q_{10} = \frac{89}{32} = 2.8 \]

Enzyme-substrate affinity as a function of temperature in six species of poikilotherms. All the blue line segments, which identify the ordinary body temperatures of the species, fall within the narrow vertical distance marked by the vertical blue bar. Thus, affinity for substrate is kept relatively constant at the respective ordinary body temperatures of the species because of the evolution of different LDH homologs.
Control endocrino de la tasa metabólica en vertebrados
A Na⁺-I⁻ symporter brings I⁻ into the cell. The pendrin transporter moves I⁻ into the colloid.

Follicular cell synthesizes enzymes and thyroglobulin for colloid.

Intracellular enzymes separate T₃ and T₄ from the protein.

Thyroglobulin is taken back into the cell in vesicles.

Thyroid peroxidase adds iodine to tyrosine to make T₃ and T₄.

Free T₃ and T₄ enter the circulation.

**KEY**
- MIT = monooiodotyrosine
- DIT = diiodotyrosine
- T₃ = triiodothyronine
- T₄ = thyroxine
TABLE 21-6 Thyroid Hormones

<table>
<thead>
<tr>
<th>Cell of origin</th>
<th>Thyroid follicle cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical nature</td>
<td>Iodinated amine</td>
</tr>
<tr>
<td>Biosynthesis</td>
<td>From iodine and tyrosine; formed and stored on parent protein thyroglobulin in colloid of follicle</td>
</tr>
<tr>
<td>Transport in the circulation</td>
<td>Bound to thyroxine-binding globulin and albumins</td>
</tr>
<tr>
<td>Half-life and degradation</td>
<td>6–7 days for thyroxine (T₄); about 1 day for triiodothyronine (T₃)</td>
</tr>
<tr>
<td>Stimulus for release</td>
<td>Tonic release</td>
</tr>
<tr>
<td>Control axis</td>
<td>Thyrotropin-releasing hormone (TRH) (hypothalamus) → thyroid-stimulating hormone (TSH) (anterior pituitary) → T₃ and T₄ (thyroid) → T₄ deiodinates in tissues to form more T₃</td>
</tr>
<tr>
<td>Target cells or tissues</td>
<td>Most cells of the body</td>
</tr>
<tr>
<td>Target receptor</td>
<td>Nuclear receptor</td>
</tr>
<tr>
<td>Whole body or tissue action</td>
<td>↑ Oxygen consumption (thermogenesis); protein catabolism in adults but anabolism in children; normal development of nervous system</td>
</tr>
<tr>
<td>Action at cellular level</td>
<td>Increases activity of metabolic enzymes and Na⁺/K⁺-ATPase</td>
</tr>
<tr>
<td>Action at molecular level (including second messenger)</td>
<td>Production of new enzymes</td>
</tr>
<tr>
<td>Feedback regulation</td>
<td>T₃ has negative feedback effect on anterior pituitary and hypothalamus</td>
</tr>
</tbody>
</table>
Efectos intracelulares

Receptor
ADN

↑ ARNm

Proteínas para el crecimiento y la maduración

↑ Na⁺, K⁺-ATPasa
↑ Enzimas respiratorias
↑ Otras enzimas y proteínas

↑ Consumo de O₂
↑ Tasa metabólica

↑ Gasto cardíaco
↑ Ventilación

↑ Ingesta alimenticia
↑ Movilización de endógenos carbohidratos, proteínas y grasa

O₂
Sustratos

↑ CO₂
↑ Urea
↓ Masa muscular
↓ Tejido adiposo

Termogénesis

Efectos globales sobre el organismo
As venous blood flows outward, it loses heat to the closely juxtaposed arterial blood, which carries the heat inward again.
(i) Maximize heat gain

(ii) Minimize heat gain

Thoracic temperature (°C)

Air temperature (°C)

Isothermal line

Flight muscle
Aorta
Insulation
Heart
Nerve cord
Air sacs
Heat exchanger
Thermal window
Ventral diaphragm
Thorax
Aorta
Abdomen
V.D.