

## Glossary: Terminology in animal and human energy metabolism

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### Introduction

The utilisation of definitions and symbols in studies of energy metabolism is not consistent nowadays. This originates on the one hand from the historical background and on the other hand from differing instructions for authors in scientific journals. The purpose of this proposal is therefore to put together basic rules for the utilisation of terms related to the field of energy metabolism. Since there is also inconsistency when using quantities and units to describe measurements, a short summary about their use is listed beforehand.

### Prefixes and units according to the International System of Units (SI)

The rules for the utilisation of prefixes and units of measurement are laid down by the Bureau International des Poids et Mesures (1998). SI units are divided in two classes, the base units and the derived units. The units mostly used in the field of energy metabolism are listed in the following Table 1.

Table 1. Units and symbols related to energy metabolism (according to Bureau International des Poids et Mesures (1998)).

<b>Base units</b>			
Base quantity	Name of unit	Symbol	Comment
Length	meter	m	
Mass	kilogram	kg	The use of the name <i>weight</i> for the unit of mass is incorrect. Weight denotes a quantity of the same nature as a force: the weight of a body is the product of its mass and the acceleration due to gravity. The terms body weight or live weight must be replaced by the terms body mass and live mass.
Time	second	s	The use of the abbreviation sec for the unit of time is not correct. The use of the units day, hour, and minute is accepted as non-SI units (see Table 2).
Temperature	kelvin	K	The use of the unit Celsius temperature is still common (see Derived units).
Substance	mole	mol	The use of the symbol M for the unit of substance is incorrect, since M is the prefix for the factor 10 <sup>6</sup> (see Table 3).

<b>Derived units</b>			
Derived quantity	Name of unit	Symbol	Comment
Energy, work, quantity of heat	joule	J	The use of the old non-SI unit calorie should be avoided, since it is not listed as an accepted non-SI unit.
Celsius temperature	degree Celsius	°C	The symbol °C is written without space between "°" and "C", but there must be a space between the digit and the symbol.

Several non-SI units are accepted for use with the International System in addition to the base and derived SI units (Table 2).

Table 2. Accepted non-SI units (according to according to Bureau International des Poids et Mesures (1998)).

Name	Symbol	Value in SI units	Comment
minute	min	1 min = 60 s	
hour	h	1 h = 60 min = 3600 s	The use of <i>hrs</i> for the plural of the symbol h is incorrect, since it does not exist a plural of a symbol.
day	d	1 d = 24 h = 86 400 s	
litre	L, l	1 L = 1 dm <sup>3</sup> = 10 <sup>-3</sup> m <sup>3</sup>	The use of the capitalised symbol L should be preferred, since it avoids possible confounding with the number 1.
tonne	t	1 t = 10 <sup>3</sup> kg	

## Prefixes

The prefixes, which are approved by the SI, cover a range from the factors 10<sup>24</sup> to 10<sup>-24</sup>. In the field of energy metabolism it is common to use prefixes ranging from 10<sup>9</sup> to 10<sup>-9</sup> (Table 3).

## Writing of SI units and prefixes

In the SI not only the use of prefixes and units are laid down, but also rules for their correct writing. The general principles for units and symbols discussed in this proposal are:

- Unit symbols are written lower case, except when the name of the unit is derived from a proper name (K for Kelvin, °C for degree Celsius, J for Joule), and for the unit of litre (L) when confounding with the number one is possible.
- Unit symbols are unaltered in the plural.
- Unit symbols are not followed by a full stop, except at the end of a sentence.
- Half-high dots or spaces are used to express a derived unit from two or more other units by multiplication (e.g. N·m or N m).
- A solidus (slash, oblique stroke, /), a horizontal line<sup>1</sup>, or a negative exponent is used to express a derived unit from two other units by division (e.g. m/s, m·s<sup>-1</sup>).
- A solidus is not followed by a multiplication or division sign on the same line, unless ambiguity is avoided by parentheses<sup>2</sup>.

Table 3. SI prefixes.

Factor	Name	Symbol	Factor	Name	Symbol
10 <sup>9</sup>	giga	G	10 <sup>-1</sup>	deci	d
10 <sup>6</sup>	mega	M	10 <sup>-2</sup>	centi	c
10 <sup>3</sup>	kilo	k	10 <sup>-3</sup>	milli	m
10 <sup>2</sup>	hecto	h	10 <sup>-6</sup>	micro	μ
10 <sup>1</sup>	deca	da	10 <sup>-9</sup>	nano	n

<sup>1</sup> Authors note: Since a horizontal line is not easily written, it is proposed to use the other two possibilities

<sup>2</sup> Authors note: Since the use of negative exponents always avoids ambiguity, its use should be preferred

According to the Guide for the Use of the International System of Units (Taylor, 1995), it is furthermore recommended that:

- A digit should precede the unit and that a space must separate the digit from the unit.
- Information is not mixed with unit names or symbols. For example the form “the water content is 20 mL·kg<sup>-1</sup>” and not “20 mL H<sub>2</sub>O·kg<sup>-1</sup>” or “20 mL of water/kg”.
- Unit names and unit symbols are not mixed. For example mmol·L<sup>-1</sup> is used and not mmol/litre.
- The digits of numerical values having more than four digits are separated into groups of three using a thin space. Commas are not used to separate digits into groups of three (e.g. 12 000 kJ and not 12,000 kJ for 12 MJ).
- The term normality and the symbol N as well as the term molarity and the symbol M are obsolete. Instead the term concentration with the derived unit mol·m<sup>-3</sup> or a related acceptable unit should be used.

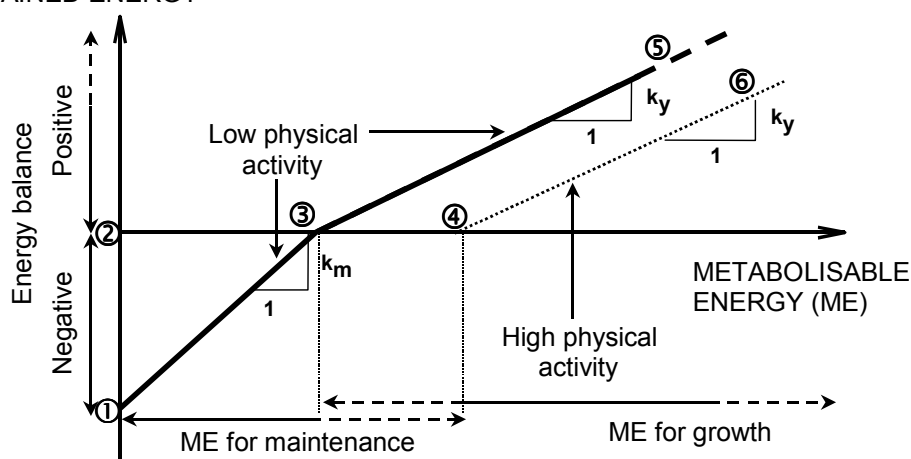
The rules for writing prefixes are:

- Prefixes are printed with no space between the prefix symbol and the unit symbol.
- The grouping formed by the prefix symbol attached to the unit symbol constitutes a new inseparable symbol (of a multiple or sub-multiple of the unit concerned), which can be raised to a positive or negative power and combined with other unit symbols to form compound unit symbols.
- Compound prefixes, i.e. prefixes formed by the juxtaposition of two or more SI prefixes, are not used.
- A prefix is never used in isolation.

## Terms and abbreviations used in energy metabolism

Sometimes the term calorie or caloric is used when describing an energetic amount. This should be avoided - since the calorie is the unit (a not accepted non-SI unit) and not the name of the measured quantity<sup>3</sup> - and the term energy or energetic be used instead of. One kcal represents approximately 4.184 kJ of energy.

RETAINED ENERGY



- |   |  |
|---|--|
| ① Fasting heat production                     | ④ ME for maintenance at high physical activity |
| ② Zero energy balance                         | ⑤ ME for growth at low physical activity       |
| ③ ME for maintenance at low physical activity | ⑥ ME for growth at high physical activity      |

Figure 1. Energy Retention in Relation to the Intake of Metabolisable Energy.

<sup>3</sup> Using caloric as a term would correspond to the use of a term like "kilogrammic" or "joulic".

All biological functions require energy. In a state of energetic balance the amount of required energy matches the amount of energy spent (retained energy equals zero, i.e. Energy balance = 0; Figure 1). Retention of energy occurs whenever intake of metabolisable energy is higher than energy expenditure, and mobilisation of energy (i.e. negative “retention”) occurs whenever the expenditure of energy is higher than the intake.

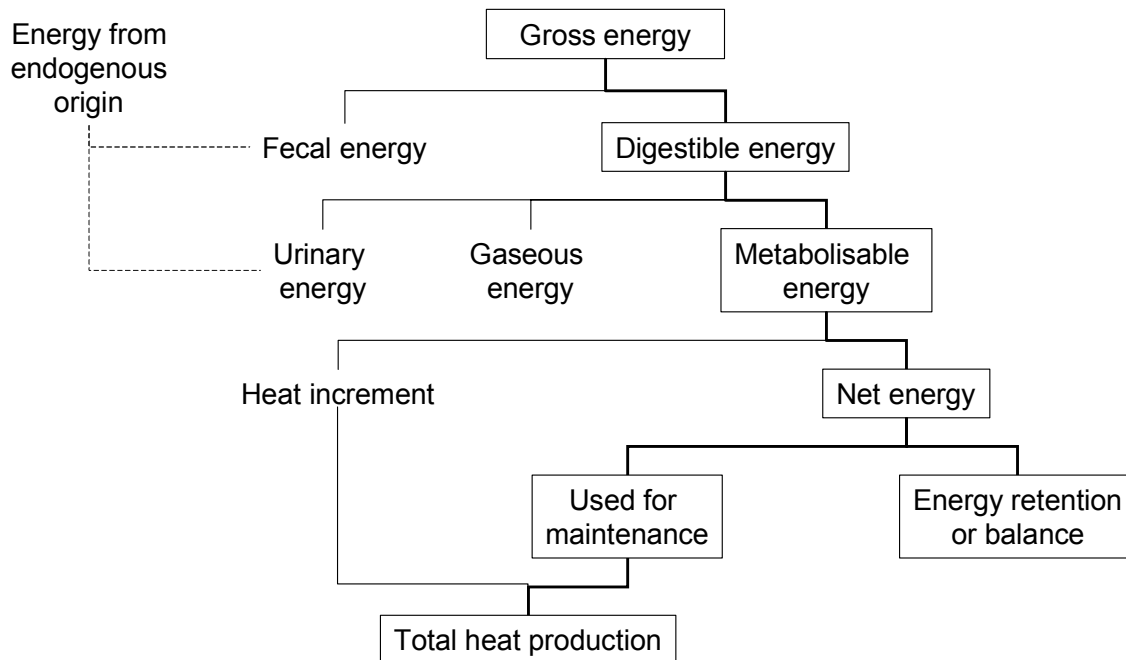


Figure 2. Energy partition of food energy.

A brief definition of each of the terms relating to the field of energy metabolism in mammals is given and an appropriate abbreviation is proposed where meaningful (Figure 1 and 2). The abbreviation for the term energy should be the capital letter E.

### Ash

The ash content is determined by burning of a known mass of a substance at 550 °C until constancy of mass.

### Basal metabolic rate (BMR) = Basal energy expenditure (BEE)

Energy requirement to sustain the body’s vital function in the awake state. The BMR in humans is measured by indirect calorimetry under highly standardised conditions: complete physical rest in supine position shortly after being awake, in thermoneutral environment, 12 h - 14 h after the last meal (i.e. post absorptive), at sexual repose, emotionally undisturbed, and without disease or fever (see also fasting energy expenditure).

### Crude fibre (CF)

The crude fibre is the fat-, nitrogen-, and ash-free residue of a food after boiling acid and alkali of defined concentration. It should be noted that the CF fraction consists of lignin, pentosan and at least a part of cellulose. However, determining acid-detergent lignin (ADL), acid-detergent fibre (ADF), and neutral-detergent fibre (NDF) allow estimating lignin, cellulose, and hemicellulose content and hence a better characterisation of the dietary fibre. Beside lignin dietary fibre is considered to consist mainly of non-starch polysaccharides

(NSP). The most precise and detailed characterisation of NSP could be given by enzymatic methods allowing determination of the NSP composition. NSP can be differentiated between soluble and insoluble fraction. The former includes gums, pectins, mucilages, and some hemicelluloses whereas the latter consists of cellulose and the majority of hemicellulose. However, it is important to notice that the proportion of these components can vary depending on the feedstuff. This is of interest for the energy metabolism since the energetic value of these components is different and the different compounds have different impact on both their own digestibility and the digestibility of other nutrients like protein which in turn affects energy digestibility (see also nitrogen-free extracts).

The heat of combustion of crude fibre (cellulose) averages  $17.8 \text{ kJ}\cdot\text{g}^{-1}$  (Brouwer, 1965).

### **Crude protein (CP)**

The crude protein content of feedstuff is defined as nitrogen content  $\times 6.25$ . This definition is based on the assumption that the average nitrogen content of protein is  $160 \text{ g}\cdot\text{kg}^{-1}$ . However, basically each protein has its own conversion factor depending on the respective amino acid composition. Therefore, the factor can (theoretically) be calculated from the amino acid composition and the N-content of each amino acid (Table 4), for instance, the factor generally used for milk protein is 6.38. It should be pointed out that analysed nitrogen includes, besides “true protein”-nitrogen, also nitrogen derived from components such as free amino acids, amines, nucleic acids and dietary fibre.

The generally accepted value of heat of combustion of crude protein is  $23.8 \text{ kJ}\cdot\text{g}^{-1}$  (Brouwer, 1965).

### **Digestible energy (DE) and energy digestibility (d(E))**

The digestible energy is the remaining energy content after subtracting the faecal energy ( $\text{GE}_{\text{faeces}}$ ) from the food energy ( $\text{GE}_{\text{food}}$ ) (compare Figure 2).

$$\text{DE} = \text{GE}_{\text{food}} - \text{GE}_{\text{faeces}}$$

Where: DE,  $\text{GE}_{\text{food}}$ ,  $\text{GE}_{\text{faeces}}$  in MJ

Accordingly, the digestibility of energy expresses the ratio between DE and  $\text{GE}_{\text{food}}$ :

$$d(\text{E}) = \frac{\text{GE}_{\text{food}} - \text{GE}_{\text{faeces}}}{\text{GE}_{\text{food}}}$$

Since faeces also contains energy derived from endogenous secretions from the intestinal tract, the terms “apparent digestible energy” and “apparent digestibility” are more accurate expressions than “digestible energy” and “digestibility”, respectively. In practice, determination of “true digestibility” is impossible, because the energy fractions of the faeces attributable to the food on the one hand and to the animal or human on the other hand are indistinguishable from one another. However, there are some techniques available (e.g. mobile nylon bag technique, fistulation technique) that may help to determine the origin of digestive energy losses.

Depending on the species and the chemical composition of the food, several formulas are available and in use for the prediction of the DE of the food.

### **Efficiency of utilisation of ME for maintenance ( $k_m$ )**

The efficiency of utilisation of ME for maintenance describes the ratio of fasting heat production to maintenance heat production when both measurements are minimal (thermal

neutrality). It is assumed that this efficiency is constant between fasting and maintenance and can be applied only in situations where animals are fed close to maintenance feeding level (see also energy expenditure for maintenance and Figure 1). Fasting animals will catabolise mainly body protein and fat in order to assure their energy requirements. With increasing energy supply (toward maintenance), dietary energy sources can be used for ATP synthesis, thereby sparing body protein and fat. The  $k_m$  should therefore be interpreted as the utilisation of dietary energy, relative to the utilisation of body stores. As a result, its value may (at least theoretically) exceed unity.

**Efficiency of utilisation of ME for protein deposition ( $k_p$ ), fat deposition ( $k_f$ ), growth ( $k_g$ ), lactation ( $k_l$ ), egg production ( $k_e$ ), fetal growth ( $k_c$ ), and wool ( $k_{wool}$ ),**

The (partial) efficiency of utilisation of ME for protein deposition, fat accretion, growth, lactation fetal growth, or wool describes the increment in energy retention (of the production characteristic concerned) resulting from one unit increase in ME intake (above maintenance). According to Figure 1 presented in the first part of this glossary, the ratio is expressed as a fraction:

$$k_y = (\Delta Y) \cdot (\Delta MEI)^{-1} \quad \text{or} \quad k_y = Y \cdot (MEI - ME_m)^{-1}$$

Where:  $\Delta$  = change in  
 $Y$  is either =  $RE_p$  = retained energy as protein  
 $RE_f$  = retained energy as fat  
 $RE_g$  = retained energy as both protein and fat or growth, respectively  
 $RE_{lac}$  = retained energy as milk  
 $RE_e$  = retained energy as eggs  
 $RE_c$  = retained energy as fetal growth  
 $RE_{wool}$  = retained energy as wool  
 $MEI$  = ME intake

**Endogenous energy loss ( $GE_{endo}$ )**

The endogenous energy loss is the amount of energy originating from the tissues and secretions of the animal, which cannot be attributed to  $GE_{food}$  and is excreted in both faeces and urine, which is measured as the material energy loss in a fasting state (see also urinary / faecal energy loss and Figure 2).

**Energy balance (EB), energy retention (RE)**

The retained energy (or the energy of useful products) is the remaining energy after subtracting all energy losses ( $GE_{faeces}$ ,  $GE_{urine}$ ,  $GE_{gas}$ ,  $Q$ ) from  $GE_{food}$  (see Figure 2). In case of a positive EB, energy is stored (or secreted) in the body as protein ( $RE_p$ ), fat ( $RE_f$ ), or both ( $RE_g$ ), milk ( $RE_{lac}$ ), eggs ( $RE_e$ ), wool ( $RE_{wool}$ ) or reproduction products ( $RE_c$ ), whereas in case of a negative EB energy is mobilised from the body.

$$EB = GE_{food} - (GE_{faeces} + GE_{urine} + GE_{gas} + Q)$$

Where: EB,  $GE_{food}$ ,  $GE_{faeces}$ ,  $GE_{urine}$ ,  $GE_{gas}$ , and  $Q$  in MJ

## Energy expenditure (Q)

The energy expenditure (or total heat production) includes the energy associated with digestive and metabolic processes (heat increment), the energy required for maintenance (including physical activity), and the energy expended in response to changes in the environment (see Figure 2). Heat production can be measured through direct or indirect calorimetry. The latter method measures the respiratory exchange (RQ-method) or the nitrogen and carbon balance (C/N-method). The RQ-method is based on the assumption that heat is produced through oxidation of nutrients (resulting in O<sub>2</sub> consumption and CO<sub>2</sub> production). Because nutrients are not completely oxidised (urea originates from protein and CH<sub>4</sub> from fermentation), the estimation of Q by the RQ-method is based on the following equation (Brouwer, 1965):

$$Q = 16.18 \cdot V_{O_2} + 5.16 \cdot V_{CO_2} - 5.90 \cdot N - 2.42 \cdot V_{CH_4}$$

Where:

Q	=	energy expenditure in kJ
V <sub>O<sub>2</sub></sub>	=	oxygen consumption in L
V <sub>CO<sub>2</sub></sub>	=	carbon dioxide production in L
N	=	urinary nitrogen excretion in g
V <sub>CH<sub>4</sub></sub>	=	methane production in L

The C/N-method is an alternative approach to estimate energy retention more directly and to calculate heat production by difference:

$$Q = ME - (RE_p + RE_f)$$

Where:

Protein accretion (g) = nitrogen balance (g) · 6.25 (see also *crude protein*)

$$Fat\ accretion(g) = \frac{carbon\ balance\ (g) - (protein\ accretion\ (g) \times 0.512)}{0.746}$$

RE<sub>p</sub> (kJ) = retained protein energy = protein accretion (g) · 23.8 kJ·g<sup>-1</sup>

RE<sub>f</sub> (kJ) = retained fat energy = fat accretion (g) · 39.8 kJ·g<sup>-1</sup>

The Q can also be estimated as residual value by subtracting the energy balance or energy retention, respectively, from metabolisable energy. The comparative slaughter technique can also be used for obtaining the energy retention in growing animals.

Heat production of a subject measured by indirect calorimetry. In adults, it can be partitioned into three main components:

- a) Basal metabolic rate (see also basal metabolic rate and maintenance energy expenditure)
- b) Thermogenesis induced by:
  1. a meal, i.e. post prandial thermogenesis or by food intake, i.e. diet(ary) induced thermogenesis (HI) (see also *heat increment*)
  2. cold exposure, i.e. shivering thermogenesis (SIT) or non shivering thermogenesis (NST) (see also thermogenesis)
  3. Drugs, hormones, nicotine, etc.
- b) Physical activity (see also energy expenditure for physical activity).

## **Energy expenditure for maintenance energy expenditure ( $ME_m$ or $NE_m$ )**

The need of metabolisable or net energy for maintenance is corresponding to the rate of energy expenditure measured (or estimated) at zero energy balance (see Figure 1). The  $ME_m$  includes the requirements of all essential body functions and moderate activity and should therefore not be interpreted as waste energy. Since its measurement lasts 24 h or more, it includes the overall diet(ary) induced thermogenesis plus a minimum (but generally unspecified) amount of voluntary muscular activity. The  $ME_m$  is often expressed in terms of metabolic body size ( $kg\ BM^{0.75}$ ). The exponent 0.75 originates from comparison of  $ME_m$  between species in mature animals. For growing animals (within a species), a much lower exponent is often found.

Maintenance energy requirement corresponds to a situation where the energy intake equals the energy output and hence no energy will be retained (i.e., as growth, milk, or eggs). Although this situation is easily defined, it is very difficult to measure, especially in producing animals. Growth, milk or egg production is “normal” physiological processes in producing animals and maintenance does not have a physiological meaning in producing animals. This also has consequences for the (extrapolated) fasting heat production and estimation of energetic efficiencies for maintenance (Figure 1). The animal only exploits the higher efficiency of energy metabolism below maintenance if it is actually fed below maintenance. The ME or NE value for maintenance for producing animals does not correspond to ① in Figure 1, but to the extrapolated value from ⑤ and ③ toward zero energy intake.

## **Energy expenditure for physical activity**

Maintenance energy requirement is often defined to include “normal activity”. As maintenance itself is virtually impossible to measure in producing animals, even more confusion is added by inclusion of the term “normal activity”. Housing, space allowance, feeding, and temperature in addition to the individual variation that may occur between animals of the same species may affect physical activity. Moreover, there are important species differences in the energy cost of physical activity. For inter-species comparisons, it is preferential to use activity-free (or standardised activity) heat production measurement such as the BMR. Different techniques exist to quantify activity (standing vs. lying, measurements of movement or force) leading to different estimations of the energy expenditure in the active and non-active state.

## **Energy intake (EI)**

The energy intake is defined as energy content per unit mass of the food multiplied with the amount of food per unit time. Depending on the energy category obtained from the energy partition model, EI can be expressed as gross (GEI), digestible (DEI), metabolisable (MEI), and net energy (NEI), respectively. Sometimes it is useful to attribute the EI to BM (kg) or metabolic body mass ( $kg^{0.75}$ ).

## **Ether extract (EE)**

Ether extract includes chemical substances that are soluble in and extracted by (petrol-) ether. The EE is not necessarily synonymous with lipid since, beside triglycerides, also organic acids, alcohols, pigments as well as resins and waxes are extracted by this method.

The widely accepted and used GE value for EE and fat respectively is  $39.8\ kJ\cdot g^{-1}$  (Brouwer, 1965).

### **Fasting energy expenditure (FQ)**

Total energy expenditure measured under conditions of zero energy intake results in a negative EB. Since this measurement usually lasts 24 h or more, the level of physical activity during the measurement should be described. Both the basal metabolic rate and FQ measure the heat production of a subject in a catabolic state. During a relatively short fasting period (such as with basal metabolic rate), glycogen will provide nutrients for oxidation whereas during longer fasting periods, body protein and lipids are the major source of nutrients for oxidation (see also basal metabolic rate).

### **Faecal energy ( $GE_{\text{faeces}}$ )**

The faecal energy is defined as heat of combustion of the faeces containing both the remaining energy of the  $GE_{\text{food}}$  after digestion and the energy deriving from endogenous secretion (see also endogenous energy loss and compare Figure 2).

### **Gaseous products energy ( $GE_{\text{gas}}$ )**

The gaseous products energy consists of the gross energy of combustible gases produced by fermentation in the digestive tract (e.g.  $\text{CH}_4$ ,  $\text{H}_2$ ).  $GE_{\text{gas}}$  as methane is produced especially in ruminants due to fermentative processes but also, to a smaller extent, in monogastric animals. The gas production can be measured in respiration chambers. For calculating the energy loss by methane and hydrogen the factor  $39.6 \text{ kJ}\cdot\text{L}^{-1}$  and  $12.8 \text{ kJ}\cdot\text{L}^{-1}$ , respectively, should be used (Brouwer, 1965).

### **Gross energy (GE)**

The quantity of heat released when a unit mass of material (nutrient, constituent of a food, whole food, excreta) is completely oxidised under high  $\text{O}_2$  pressure by means of a bomb calorimeter is known as gross energy or heat of combustion, respectively (see Figure 2).

If no bomb calorimeter is available but the nutrient composition of feed is known, GE can be predicted fairly accurately by the following formulas:

$$GE = 23.9 \cdot CP + 39.8 \cdot EE + 20.1 \cdot CF + 17.5 \cdot \text{NfE}$$

Where: GE of DM in  $\text{kJ}\cdot\text{kg}^{-1}$   
CP, EE, CF, NfE of DM in  $\text{g}\cdot\text{kg}^{-1}$

(Schiemann, 1988)

$$GE = 17.35 + (234.46 \cdot EE) + (62.80 \cdot CP) - (184.22 \cdot \text{Ash})$$

Where: GE of DM in  $\text{kJ}\cdot\text{kg}^{-1}$   
EE, CP, Ash in % of DM

(Ewan, 1989)

Alternatively, the GE value can be calculated from the GE energy content of the constituents. One mol of glucose (180 g) yields  $2820 \text{ kJ}\cdot\text{mol}^{-1}$ . As a monosaccharide, this results in  $15.7 \text{ kJ}\cdot\text{g}^{-1}$  and as a polysaccharide (such as starch) in  $2820/(180-18) = 17.4 \text{ kJ}\cdot\text{g}^{-1}$ . On average, the GE content of protein is  $23.6 \text{ kJ}\cdot\text{g}^{-1}$  but this depends on the amino acid composition (Table 4). The GE value of lipid depends on the fatty acid composition (primarily chain length). The GE of free fatty acids ( $\text{kJ}\cdot\text{mol}^{-1}$ ) can be calculated as  $GE = 653n - 166d - 421$ , where n is the number of carbon atoms/fatty acid, and d the number of double bonds (Livesey, 1984). The molecular mass ( $\text{g}\cdot\text{d}^{-1}$ ) of a free fatty acid is  $14n - 2d + 10$ . The GE value of lipid ( $\text{kJ}\cdot\text{g}^{-1}$ ) can

then be calculated from the GE value of 3 moles of free fatty acids, the GE value of glycerol ( $1660 \text{ kJ}\cdot\text{mol}^{-1}$ ,  $92 \text{ kJ}\cdot\text{mol}^{-1}$ ) under elimination of 3 mol of water.

*Table 4. GE value of individual amino acids, as protein ( $\text{kJ}\cdot\text{g}^{-1}$ ) (After Livesey, 1984), as well as nitrogen content of individual amino acids, as protein ( $\text{g}\cdot\text{kg}^{-1}$ ).*

Amino acid	$\text{kJ}\cdot\text{g}^{-1}$	$\text{g N}\cdot\text{kg}^{-1}$	Amino acid	$\text{kJ}\cdot\text{g}^{-1}$	$\text{g N}\cdot\text{kg}^{-1}$
Isoleucine	31.6	124	Arginine	23.9	359
Leucine	31.6	124	Histidine	24.6	306
Lysine	28.7	219	Alanine	22.8	197
Methionine	21.2	107	Aspartate	14.0	122
Cysteine	21.6	136	Asparagine	16.9	246
Phenylalanine	31.6	95	Glutamate	17.4	109
Tyrosine	27.2	86	Glutamine	20.1	219
Threonine	20.3	139	Glycine	17.0	246
Tryptophan	30.2	150	Proline	28.1	144
Valine	29.5	141	Serine	16.6	161

### Heat balance = Thermal equilibrium

The body heat balance describes the net rate at which a body generates and exchanges heat with its environment according to the following formula:

$$H = (R + C + E) + W + S$$

where	H	=	total amount of generated heat
	R	=	heat release by radiation
	C	=	heat release by convection and conduction
	E	=	heat release by transpiration
	W	=	heat which was generated by external work
	S	=	heat change of the body

R, C, and E together correspond to Q.

### Heat increment (HI)

The heat increment is known as the increase in heat production above the level represented by basal metabolism if the animal is given food. The HI is the amount of heat released due to the energy costs of digestive and metabolic processes (see Figure 2). Therefore, the HI varies considerably depending on the nature of the food, the species consuming the feedstuff, and the processes for which nutrients are used. The HI is not used for productive processes but can be used to maintain body temperature in cold environments (see also energy expenditure).

$$HI = (\Delta Q) \cdot (\Delta EI)^{-1}$$

Where:  $\Delta$  = change in Q and EI in MJ

### Metabolisable energy (ME) and energy metabolisability (m(E))

The metabolisable energy is the remaining energy after subtracting  $GE_{urine}$  and  $GE_{gas}$  from DE (see Figure 2). In non-ruminants, the gaseous products are generally ignored because they represent only a small fraction of DE (usually between 0.1 and 3.0 percent of DE). It should be noted that during the fermentative processes in the rumen a certain amount of heat is generated which could not be distinguished from total heat production. Theoretically this energy loss should also be included in the calculation:

$$ME = GE_{food} - (GE_{faeces} + GE_{urine} + GE_{gas})$$

Where: ME,  $GE_{food}$ ,  $GE_{faeces}$ ,  $GE_{urine}$ ,  $GE_{gas}$  in MJ

Accordingly, the metabolisability of energy expresses the ratio between ME and  $GE_{food}$ :

$$m(E) = \frac{GE_{food} - (GE_{faeces} + GE_{urine} + GE_{gas})}{GE_{food}}$$

Depending on the species and the knowledge about the chemical composition of the food, several equations are available for the prediction of the ME from diet composition.

### Net energy (NE)

The net energy of a food is the remaining energy of the  $GE_{food}$  after subtraction of  $GE_{faeces}$ ,  $GE_{urine}$ , and  $GE_{gas}$  as well as heat increment and includes therefore usable energy for both maintenance ( $ME_m$  or  $NE_m$ ) and production (ER, EB) (see Figure 2). It should be stressed that of the heat lost by the animal, only the heat increment is waste energy whereas (part of) the heat expenditure used for maintenance is a prerequisite for a positive EB.

$$NE = GE_{food} - (GE_{faeces} + GE_{urine} + GE_{gas} + HI)$$

Where: NE,  $GE_{food}$ ,  $GE_{faeces}$ ,  $GE_{urine}$ ,  $GE_{gas}$  and HI in MJ

Depending on the species and the chemical composition of the food, several formulas are available and in use for the prediction of the NE of the food.

### Nitrogen-free extract (NfE)

The nitrogen-free extract is defined as residual value after subtracting ash, crude protein, ether extract, and crude fibre from the dry matter. It is assumed to represent the carbohydrate fraction of the feed and contains therefore starch (amylose and amylopectin), monosaccharides but also high percentage of the dietary fibre (compare: crude fibre). Analogues to the components of the non-starch-polysaccharides the ratio between amylose and amylopectin may have an effect on energy digestibility.

For example the GE of NfE is on average 17.6, 16.6, and 15.6  $\text{kJ}\cdot\text{g}^{-1}$  for starch, saccharose, and glucose, respectively (Brouwer, 1965).

### **Overall efficiency of utilisation of ME (k)**

The overall efficiency of utilisation of ME describes the relationship between RE or EB and the total ME intake. In this calculation, also the  $ME_m$  is included. According to Figure 1 presented in the first part of this glossary, the ratio is expressed as a fraction:

$$k = RE \cdot MEI^{-1}$$

where        RE    =    total retained energy  
              MEI   =    total ME intake

### **Respiratory Quotient (RQ), Respiratory exchange ratio (RER)**

The respiratory quotient is the ratio of metabolic gas exchange from nutrient catabolism in living cells ( $CO_2$  production divided by  $O_2$  consumption). From empirical equations, the RQ of carbohydrate is calculated as 1.00, that of fat as 0.70, and that of protein as 0.81, respectively. When measurements are performed over a long period (i.e. in animals), the RQ corresponds to the RER, which defines the gas exchange at the lungs. For example during high intensity exercise, the RQ does not always correspond to the RER, since  $CO_2$  production from lactic acid buffering adds extra  $CO_2$  to the expired air and the RER can increase to well above 1.00. In addition, fatty acid synthesis is accompanied by a RQ greater than 1.00. For example, synthesis of 1 mol tripalmitin requires 11.5 mol  $O_2$  and releases 33 mol  $CO_2$  (RQ = 2.8). As a result, in growing animals the overall RQ (of catabolic and anabolic processes) can exceed 1.00.

### **Resting metabolic rate (RMR) = resting energy expenditure**

Rate of energy expenditure at rest measured under non-standardised conditions, e.g., lying down or comfortably sitting, some hours after a meal (generally variable in composition), with possible previous physical activities. Therefore, RMR must be greater than basal energy expenditure primarily because part of the postprandial thermogenic response is included in the RMR measurement.

### **Thermogenesis**

Thermogenesis is the increase in energy expenditure (heat production) in response to various stimuli. When the ingestion of a meal is the stimulus, the process can be referred to as postprandial thermogenesis, thermic effect of a meal or heat increment. When the chronic effect of a diet is the stimulus, the overall response can be referred to as diet(ary) induced thermogenesis (DIT). A change in environmental temperature (e.g., cold exposure) may induce (non-shivering) thermogenesis.

### **Urinary energy ( $GE_{urine}$ )**

The urinary energy is the heat of combustion of the urine, which is mainly present in nitrogen-containing substances (i.e., urea, uric acid, creatine and creatinine). Under normal conditions,  $GE_{urine}$  represents a small fraction of the gross energy intake but could be affected by several factors, particularly by the nitrogen intake. It should be noted that almost all urinary energy is derived from endogenous sources (compare Figure 2).

Besides the determination of  $GE_{urine}$  through bomb calorimetry,  $GE_{urine}$  can also be reliably estimated through prediction equations (e.g. Hoffmann & Klein (1980)) that are based on the nitrogen and carbon concentrations of the urine.

Because the faeces and urine are voided together, it is difficult to separate these two fractions in poultry.

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