I. Definition

A. The energy content of feedstuffs

1. In animal nutrition, we are interested in the chemical (molecular) energy of feedstuffs
2. Heat energy can be determined by bomb calorimetry
3. One calorie raises the temperature of 1 g of water 1°C (i.e., 14.5 to 15.5 °C); a kilocalorie (kcal) raises 1000 g or water 1 °C

Bomb calorimetry

IUPAC has adopted the Joule: 1 Joule is 107 ergs (0.239 calories), and 1 kcal = 4.185 kJoules

In nonruminant diet formulation, we will deal largely with the kcal.
In ruminant nutrition, we will deal primarily with the Mcal.

II. From gross energy to net energy

A. All materials containing carbon and hydrogen that can be oxidized to CO₂ and water represent potential energy for animals. We refer to this energy value as the gross energy content of a feedstuff.

C₆H₁₂O₆ + 6O₂ → 6H₂O + 686 kcal/mole (heat)

B. Not all of the gross energy is available to the animal for use.

- Fecal energy
- Urinary energy
- Heat of nutrient metabolism
- Digestible energy
- Metabolizable energy
- Net energy
- Maintenance
- Production

Gross Energy in feed consumed

- a. Basal metabolism
- b. Involuntary activity
- c. Body heat (warmth)
- d. Heat loss (cooling)

- a. Tissue growth
- b. Reproduction
- c. Eggs
- d. Work
- e. Milk
Digestibility: 
\[
\frac{(\text{input} - \text{fecal output})}{\text{input}} \times 100\% 
\]

Nutrient Requirements

C. The chemical composition of ingredients dictate the digestible and metabolizable energy content of a feed.

1. Carbohydrates
   a. Monosaccharides, disaccharides, polysaccharides
   b. Cellulose, hemicellulose
   c. Lignin

2. Fats
   a. Degree of saturation
   b. Mono, di and triglycerides; fatty acid location on the glycerol backbone

3. Amino Acids (glucogenic and ketogenic)

Energy

D. Carbohydrates as Energy Sources

1. Polysaccharides from cereal grains, and grain products such as wheat middlings
   A. Starch: amylose (straight chain polymer) and amylopectin (branched chain polymer)
   B. Nonstarch polysaccharides (NSP) (Fiber): cellulose, hemicellulose, lignin.
   Much of the dietary fiber is indigestible.

Energy

2. Starch Digestion

A. Enzyme dependent: metabolic pathways utilize monosaccharides to generate ATP

1. Amylase (salivary, pancreatic)
2. Oligo-1,6-glucosidase
3. Disaccharidases
   a. lactase: glucose and galactose
   b. maltase: glucose and glucose
   c. sucrase: glucose and fructose
Digestive enzymes convert complex CHO into monosaccharides that can be metabolized by the animal to generate chemical energy.

**Amylose:**
- Soluble in hot water
- Glucose units linked through α-1-4 linkages; straight chain

Amylose is digested by **salivary and pancreatic amylase** to yield the disaccharide, maltose.

**Maltose** is digested by **maltase** (α-glucosidase) into the individual glucose units that are readily absorbed by the intestinal epithelial cell.

**Amylopectin:**
- Insoluble in hot water
- Glucose units linked through α-1-4 linkages; but, contains branches due to α-1-6 linkages.

The α-1-6 linkages are digested by **intestinal oligo-1,6-glucosidase** to yield simple glucose for absorption.

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**Energy**

E. Lipids (Fats and Oils) as Energy Sources

1. Fats: choice white grease, animal fat, beef tallow, lard, restaurant grease, vegetable oils
   - a. Digestion and absorption are critical
      1. **Lingual lipase**
      2. Triglycerides are emulsified by **bile salts** and then attacked by **pancreatic lipase**.
      3. Products are free fatty acids and monoacylglycerol.

Pancreatic lipase is specific for the 1 and 3 positions of the triglyceride, and results in a 2 monoacylglycerol + free fatty acids.

\[
\begin{align*}
\text{FA-}^1\text{C} & \rightarrow \text{FA-}^1\text{C} \oplus \text{FA-}^2\text{C} \\
\text{FA-}^3\text{C} & \rightarrow \text{FA-}^3\text{C} \oplus \text{FA-}^2\text{C} \\
\text{C} & \rightarrow \text{C} \oplus \text{FA-}^2\text{C} \\
\text{TRI} & \rightarrow \text{DI} \oplus \text{DI} \oplus \text{MONO}
\end{align*}
\]

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\end{align*}
\]

If the FA at positions 1/3 are unsaturated, the ME value of the fat is lower because saturated FA are less readily absorbed than unsaturated FA, and unsaturated FA are more readily absorbed as the 2 monoacylglycerol.
Lard
\[ ^{1}\text{C-FA(unsaturated)} \]
\[ \text{FA-}^{2}\text{C} \]
\[ ^{3}\text{C-FA(unsaturated)} \]
Absorbability: 92%

Beef Tallow
\[ ^{1}\text{C-FA(saturated)} \]
\[ \text{FA-}^{2}\text{C} \]
\[ ^{3}\text{C-FA(saturated)} \]
Absorbability: 70%

4. Fatty acids and monoacylglycerol are incorporated into micelles

5. Micelles are passively absorbed

6. Passage to lymphatic system (triglycerides) or the portal blood (medium and short chain fatty acids).

b. Absorption of fats depends on:
   1. Chain length
   2. Degree of saturation
   3. Arrangement of saturated and unsaturated fatty acids on the glycerol molecule.

III. Dietary fatty acid profiles influence metabolic events

A. Fatty acids from dietary fats/oils are incorporated into cellular lipids.
   1. Fatty acids are incorporated into cells and tissues.

   Feeding linoleic acid will load tissues with linoleic acid.
Energy

Soybean oil is high in linoleic acid...

<table>
<thead>
<tr>
<th>Fat Source</th>
<th>Diet</th>
<th>Adipose Tissue</th>
<th>Skeletal Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef Tallow</td>
<td>11.71</td>
<td>9.06</td>
<td>10.47</td>
</tr>
<tr>
<td>Fish Oil</td>
<td>14.85</td>
<td>9.37</td>
<td>7.08</td>
</tr>
<tr>
<td>Soybean Oil</td>
<td>69.45</td>
<td>46.58</td>
<td>32.00</td>
</tr>
</tbody>
</table>

1 Each diet contained 10% of the indicated fat source.
2 Linoleic acid as a percentage of the total fatty acid content in the diets and tissues.

Energy

Fish oil is high in omega-3 fatty acids...

<table>
<thead>
<tr>
<th>Fat Source</th>
<th>Diet</th>
<th>Adipose Tissue</th>
<th>Skeletal Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef Tallow</td>
<td>&lt; 0.10</td>
<td>&lt; 0.10</td>
<td>&lt; 0.10</td>
</tr>
<tr>
<td>Soybean Oil</td>
<td>&lt; 0.10</td>
<td>&lt; 0.10</td>
<td>&lt; 0.10</td>
</tr>
<tr>
<td>Fish Oil</td>
<td>6.90</td>
<td>3.46</td>
<td>4.55</td>
</tr>
</tbody>
</table>

1 Each diet contained 10% of the indicated fat source.
2 Eicosapentaenoic acid as a percentage of the total fatty acid content in the diets and tissues.

Energy

What about beef tallow and stearic acid (18:0)?

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<th>Adipose Tissue</th>
<th>Skeletal Muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef Tallow</td>
<td>17.09</td>
<td>11.31</td>
<td>11.16</td>
</tr>
<tr>
<td>Soybean Oil</td>
<td>2.92</td>
<td>8.43</td>
<td>11.22</td>
</tr>
<tr>
<td>Fish Oil</td>
<td>3.81</td>
<td>11.07</td>
<td>11.39</td>
</tr>
</tbody>
</table>

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2 Stearic acid as a percentage of the total fatty acid content in the diets and tissues.

Energy

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C. Why important?
1. Meat quality
   a. Body composition
   b. Cutability
   c. “Off flavors”
   d. Shelf life

2. Consumer Appeal
   a. Heart healthy eggs, meat

3. Therapeutic nutritional intervention

4. Energetic efficiency

IV. The Heat Increment and Fat

A. An energy (heat) loss to the animal, but NOT a waste.
   1. Can be used for maintenance heat.
   2. Fats have a lower heat increment
      a. Substitution of fat for CHO increases gain and efficiency

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V. The Extra-caloric Effect of Fat

A. Fat slows the passage rate of digesta.
   1. Digestibility of other nutrients increased.
      a. Proteins/amino acids

Dietary Fat: 3.2 to 12.2%

Ileal Digestibility: 80.7 to 83.3%