TABLE 8.1 Main digestive enzymes

Recommended name	Trivial name	Systematic name	Number	Source	Substrate
A. *Enzymes hydrolysing peptide links*					
Pepsin	—	—	3.4.23	Gastric mucosa	Proteins and peptides
Chymosin	Rennin	—	3.4.23.4	Gastric mucosa (young calves)	Proteins and peptides
Trypsin	—	—	3.4.21.4	Pancreas	Proteins and peptides
Chymotrypsin	—	—	3.4.21.1	Pancreas	Proteins and peptides
Carboxypeptidase A	Carboxypeptidase	Peptidyl-L-amino-acid hydrolase	3.4.12.2	Small intestine	Peptides
Aminopeptidases	—	α-Aminoacyl-peptide hydrolases	3.4.11	Small intestine	Peptides
Dipeptidases	—	Dipeptide hydrolases	3.4.13	Small intestine	Dipeptides
B. *Enzymes hydrolysing glycoside links*					
α-Amylase	Diastase	1, 4-α-D-Glucan glucanohydrolase	3.2.1.1	Saliva, pancreas	Starch, glycogen, dextrin
α-Glucosidase	Maltase	α-D-Glucoside glucohydrolase	3.2.1.20	Small intestine	Maltose
Oligo-1, 6-glucosidase	Isomaltase	Dextrin 6-α-glucanohydrolase	3.2.1.10	Small intestine	Dextrins
β-Galactosidase	Lactase	β-D-Galactoside galactohydrolase	3.2.1.23	Small intestine	Lactose
β-Fructofuranosidase	Sucrase	β-D-Fructofuranoside fructohydrolase	3.2.1.26	Small intestine	Sucrose
C. *Enzymes acting on ester links*					
Triacylglycerol lipase	Lipase	Triacylglycerol acyl-hydrolase	3.1.1.3	Pancreas	Triglycerides
Cholesterol esterase	—	Sterol-ester hydrolase	3.1.1.13	Pancreas and small intestine	Cholesterol esters
Phospholipase A_2	Lecithinase A	Phosphatide 2-acyl-hydrolase	3.1.1.4	Pancreas and small intestine	Lecithins and Cephalins
Lysophospholipase	Lysolecithinase	Lysolecithin acyl-hydrolase	3.1.1.5	Small intestine	Lysolecithin
Deoxyribonuclease	DNAase	Deoxyribonucleate 5′-oligonucleotidohydrolase	3.1.4.5	Pancreas and small intestine	DNA
Ribonuclease I	RNAase	Ribonucleate 3′-pyrimidino-oligonucleotidohydrolase	3.1.4.22	Pancreas and small intestine	RNA
Nucleosidase	—	N-Ribosyl-purine ribohydrolase	3.2.2.1	Small intestine	Nucleosides
Phosphatases	—	—	3.1.3	Small intestine	Orthophosphoric acid esters

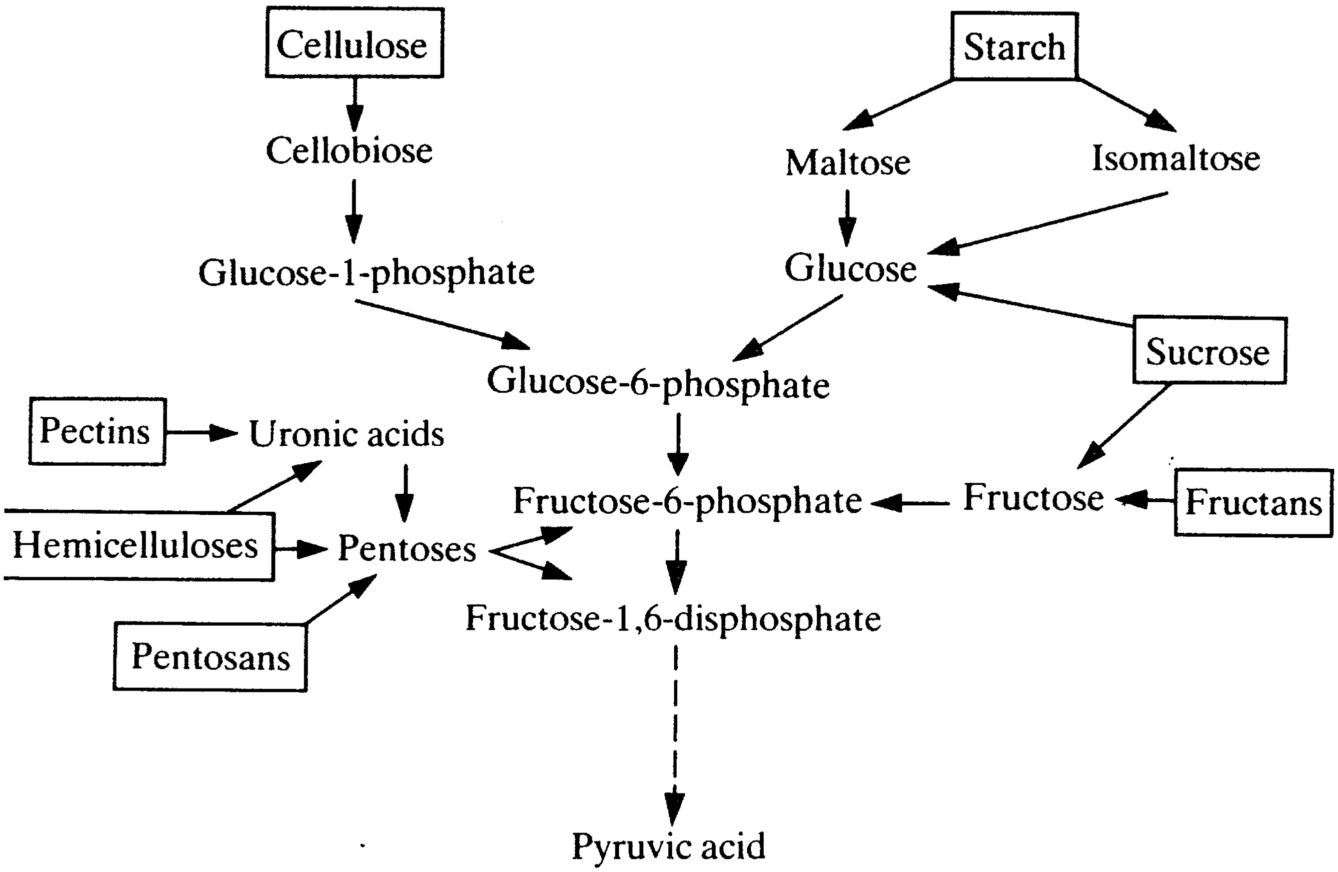


Fig. 8.2. Conversion of carbohydrates to pyruvate in the rumen.

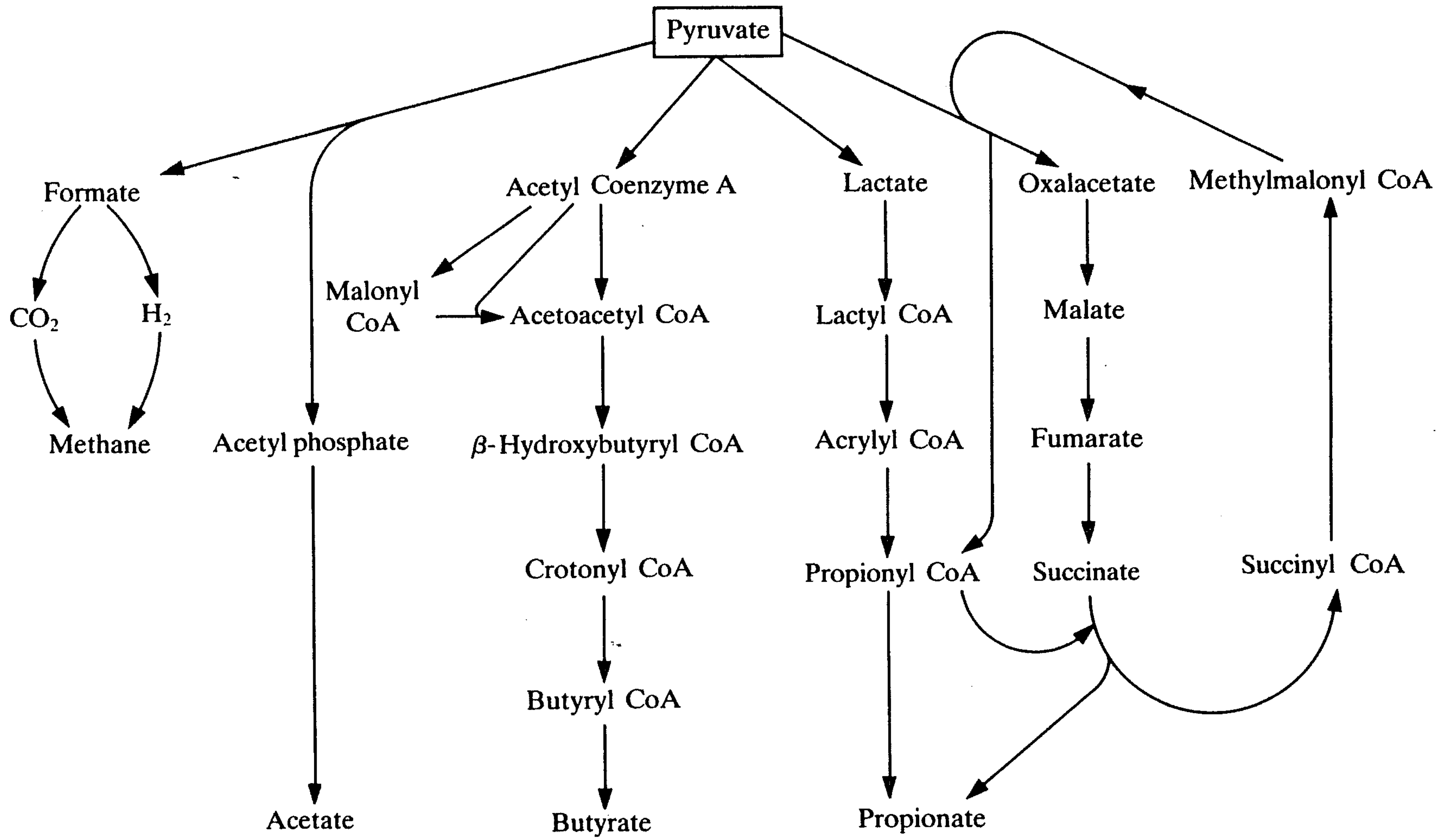


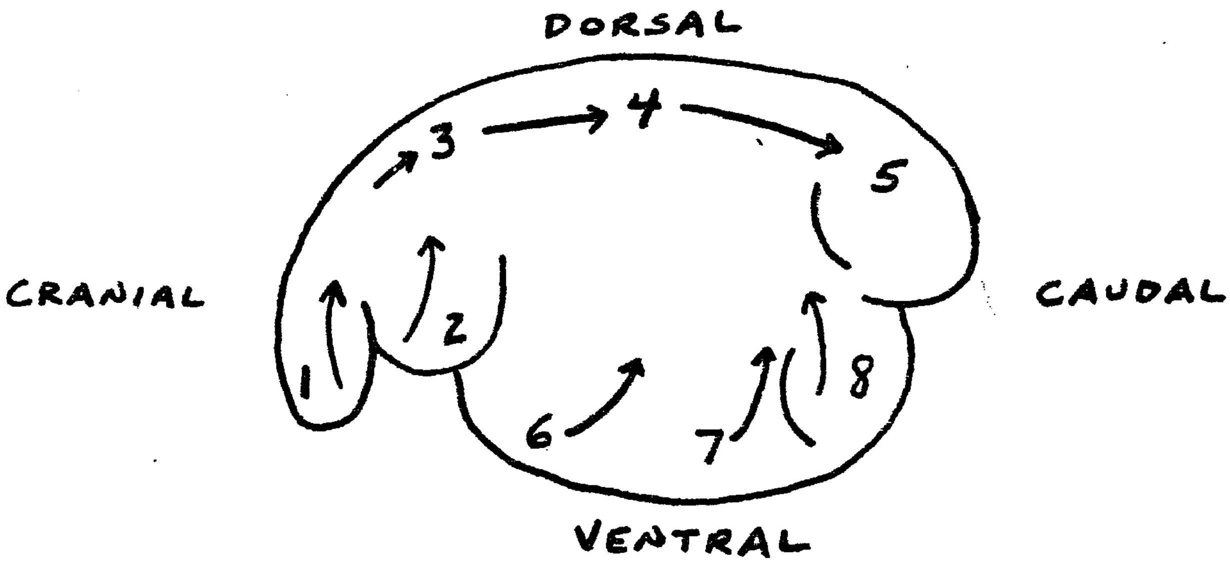
Fig. 8.3. Conversion of pyruvate to volatile fatty acids in the rumen.

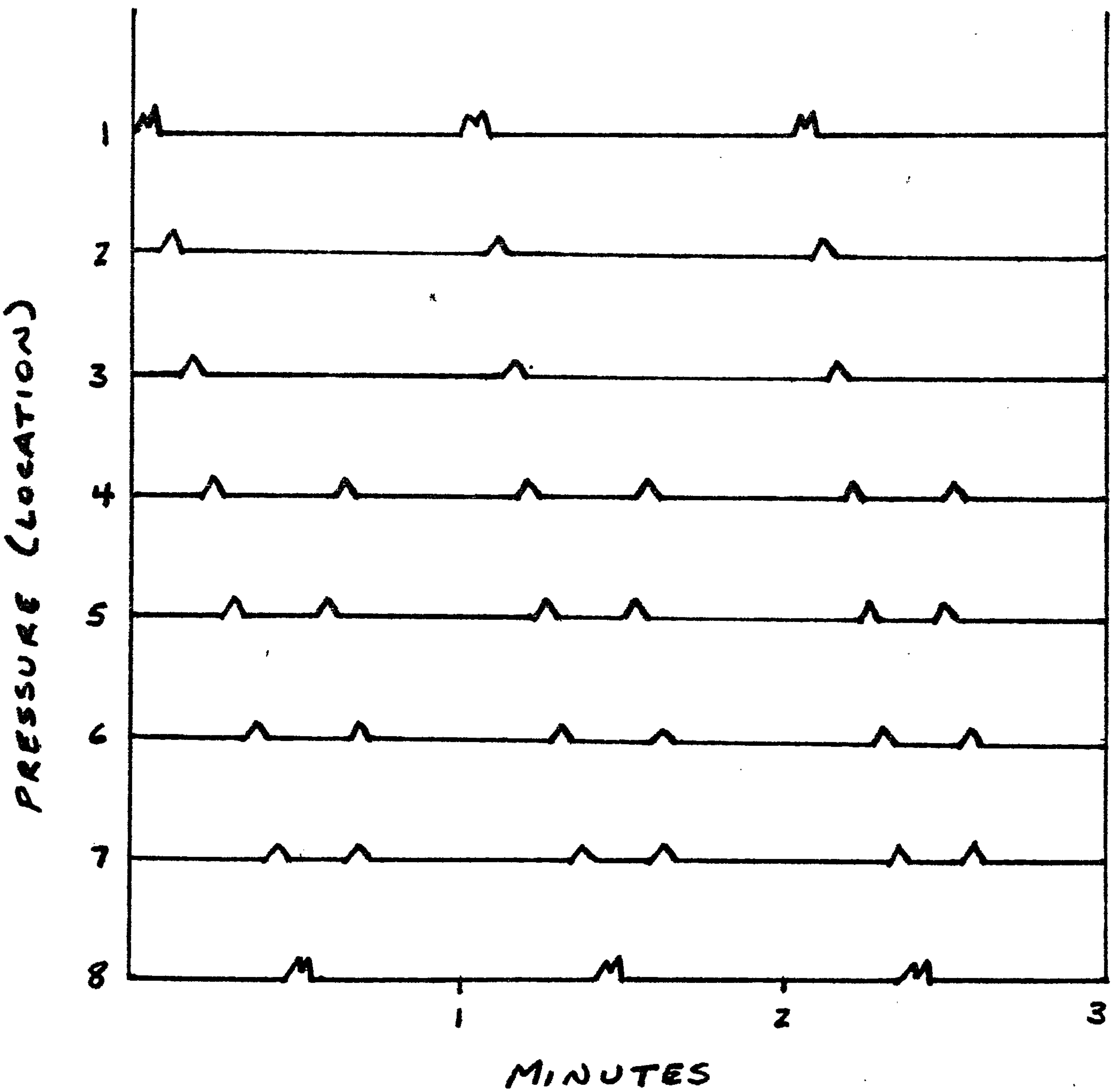
TABLE 8.3 Typical rumen bacteria, their energy sources and fermentation products *in vitro*

Species	*Description*	*Typical energy source*	*Typical fermentation products*†						*Alternative energy sources*
			Acetic	*Propionic*	*Butyric*	*Lactic*	*Succinic*	*Formic*	
Bacteroides succinogenes	Gram negative rods	Cellulose	+				+	+	Glucose, (starch)
Ruminococcus flavefaciens	Catalase negative streptococci with yellow colonies	Cellulose	+				+	+	Xylan
Ruminococcus albus	Single or paired cocci	Cellobiose	+					+	Xylan
Streptococcus bovis	Gram positive, short chains of cocci; capsulated	Starch				+			Glucose
Bacteroides ruminicola	Gram negative, oval or rod	Glucose	+				+	+	Xylan, starch
Megasphaera elsdenii	Large cocci, paired or in chains	Lactate	+	+	+				Glucose, glycerol

† Excluding gases

RUMEN CONTRACTIONS





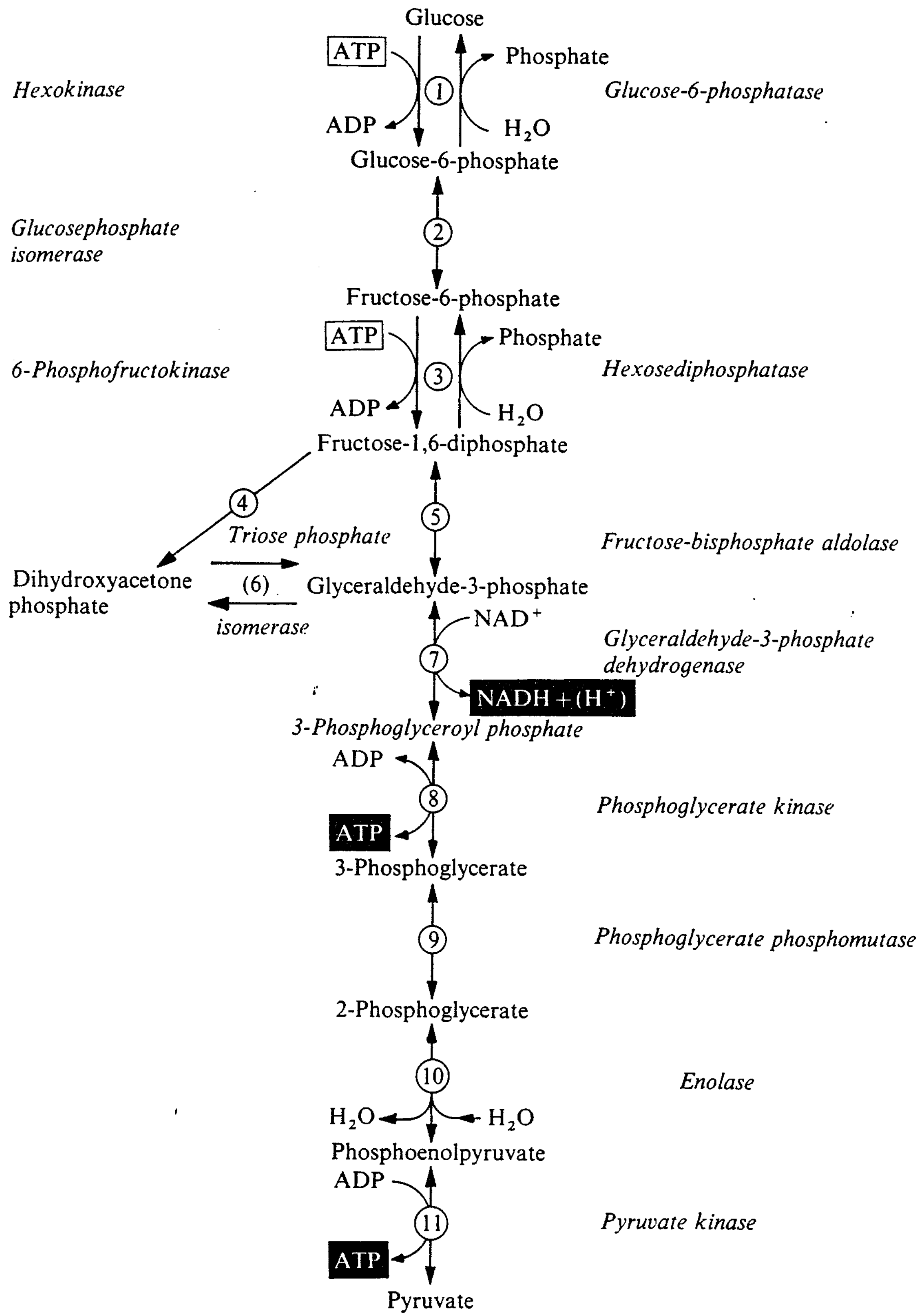


Fig. 9.3. The glycolytic pathway.

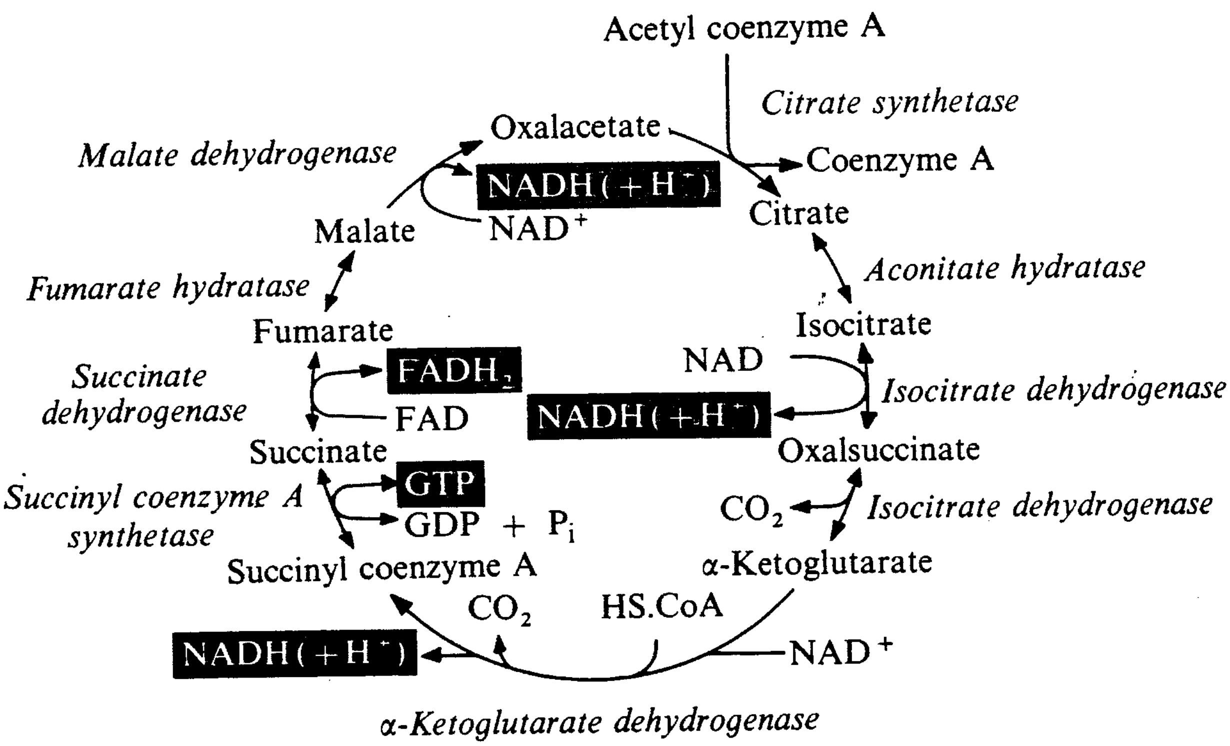


Fig. 9.4. The tricarboxylic acid cycle.

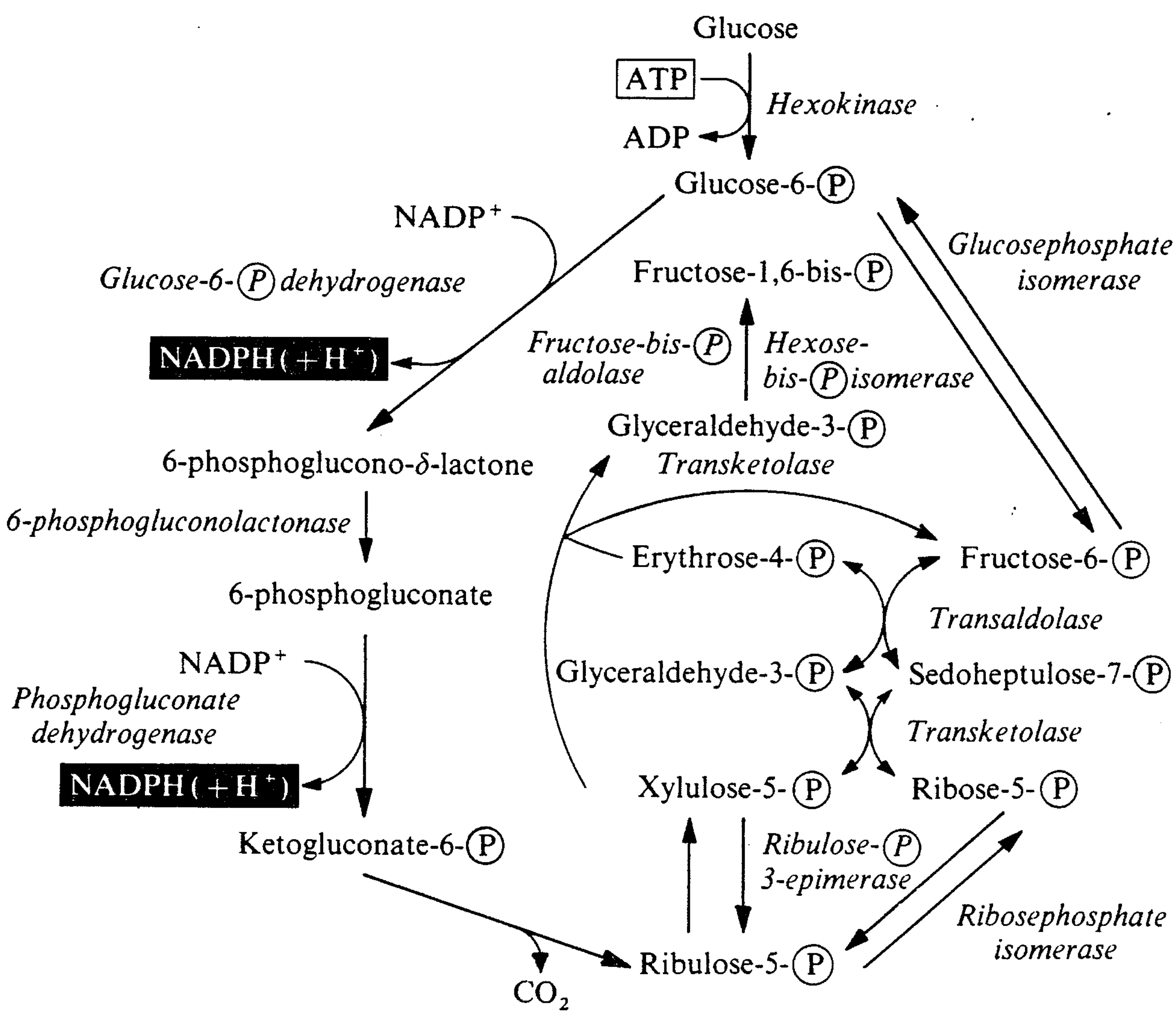


Fig. 9.5. The pentose phosphate pathway.

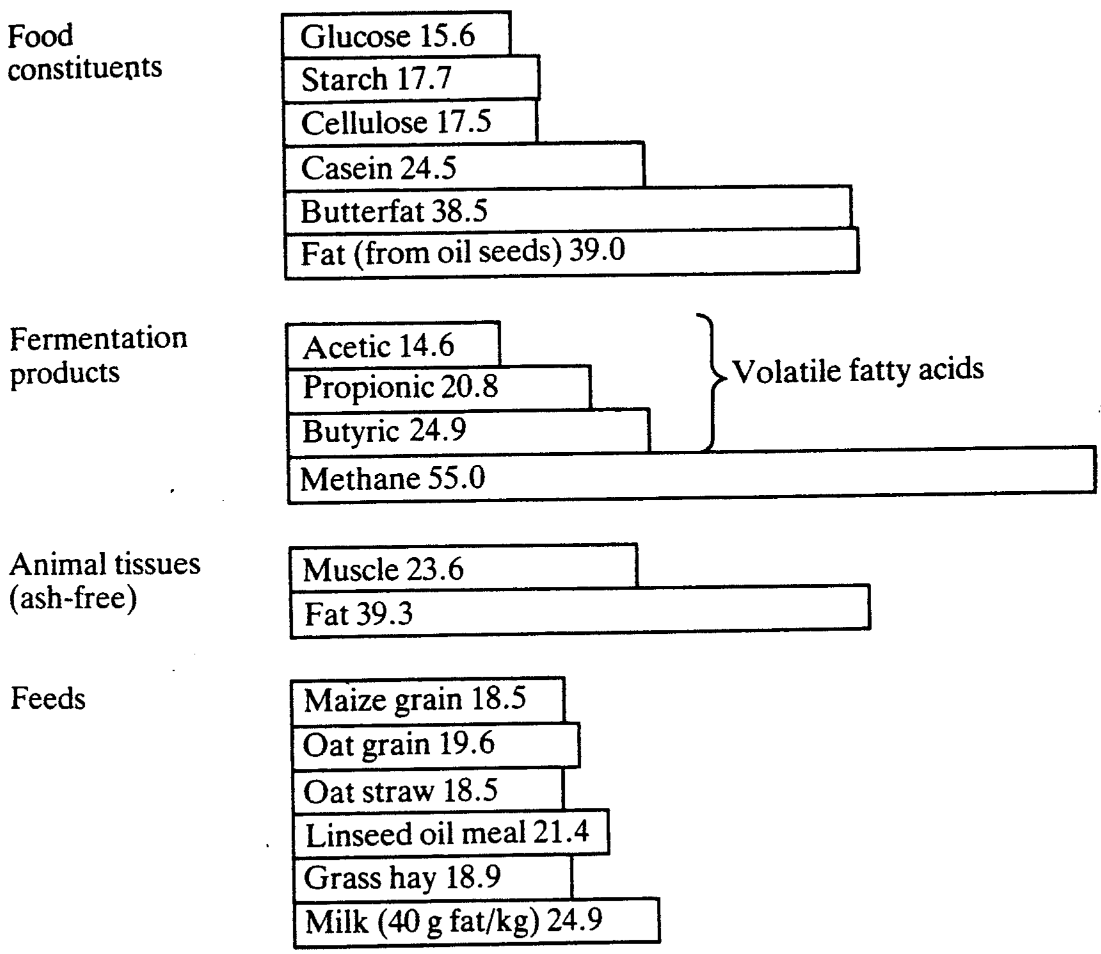


Fig. 11.1. Some typical gross energy values (MJ/kg dry matter)

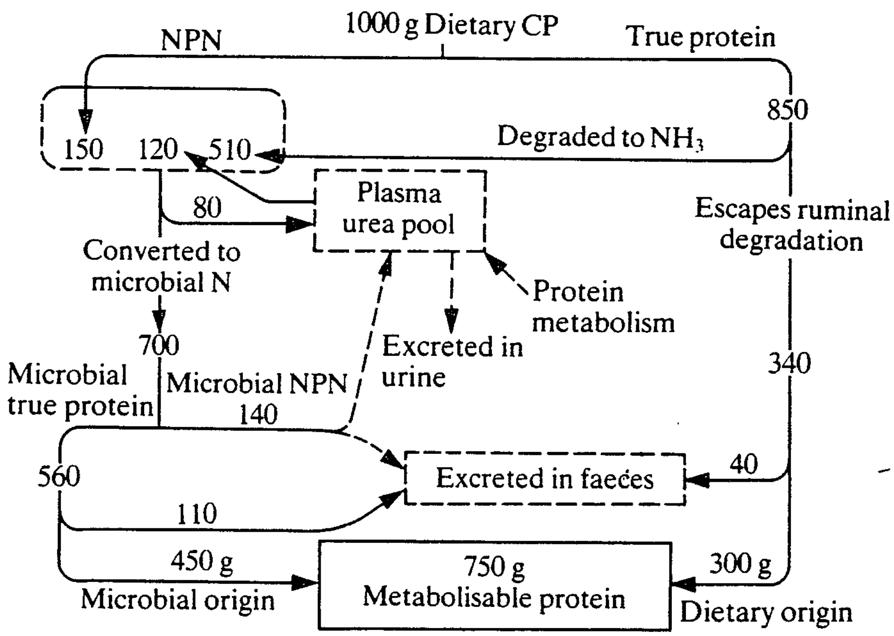


Fig. 13.2. Calculation of 'Metabolisable Protein' of diet. (From L. D. Satter and R. E. Roffler, 1977 in '*Protein Metabolism and Nutrition*', EAAP Pub. No. 22).

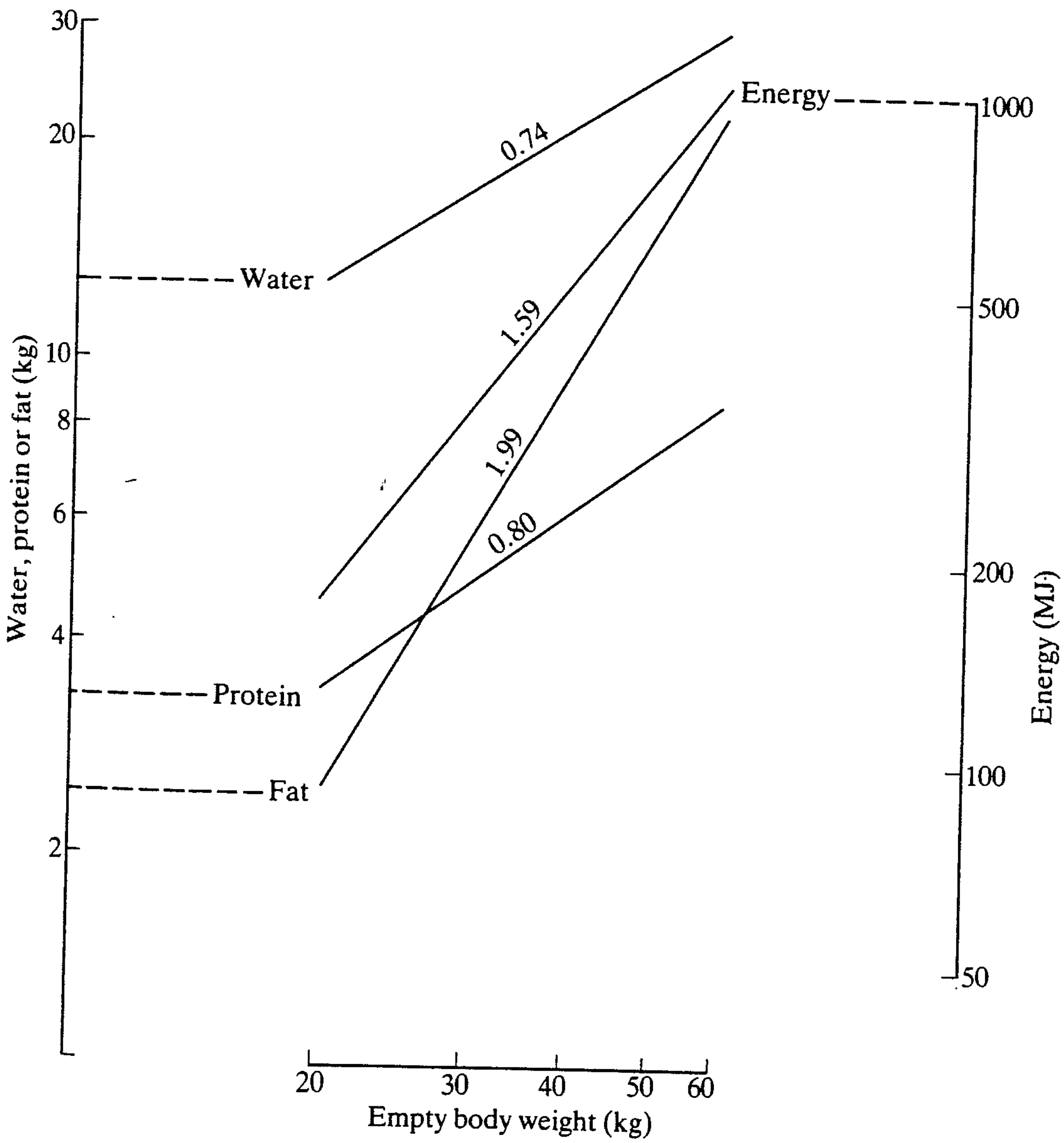


Fig. 14.4. Growth coefficients for water, protein, fat (ether extract) and energy in the whole empty body of sheep. (From J. T. Reid *et al.*, 1968. In *Body Composition in Animals and Man*. Publ. Nat. Acad Sci. No. 1598.)

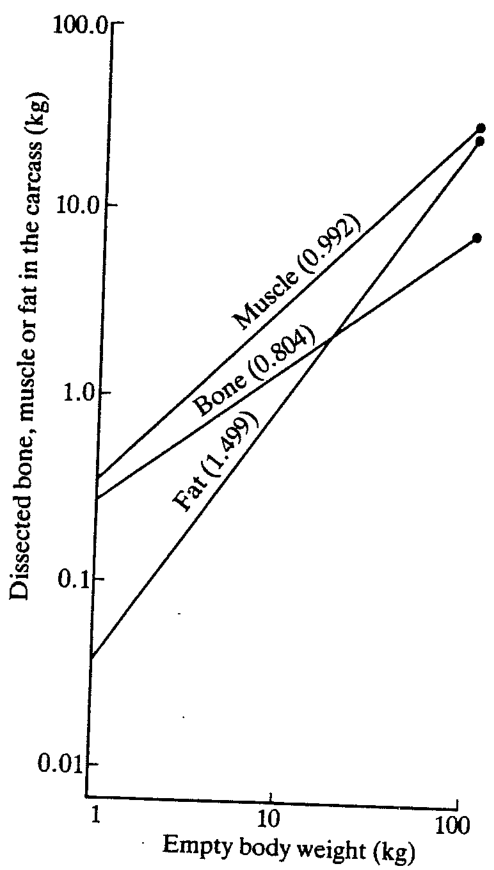


Fig. 14.5. Growth coefficients for bone, muscle and fat in the carcasses of pigs. (Calculated from the data of C. P. McMeekan and R. W. Pomeroy by N. M. Tulloh, 1964. In *Carcass Composition and Appraisal of Meat Animals* Commonwealth Scientific and Industrial Research Organisation, Australia.)

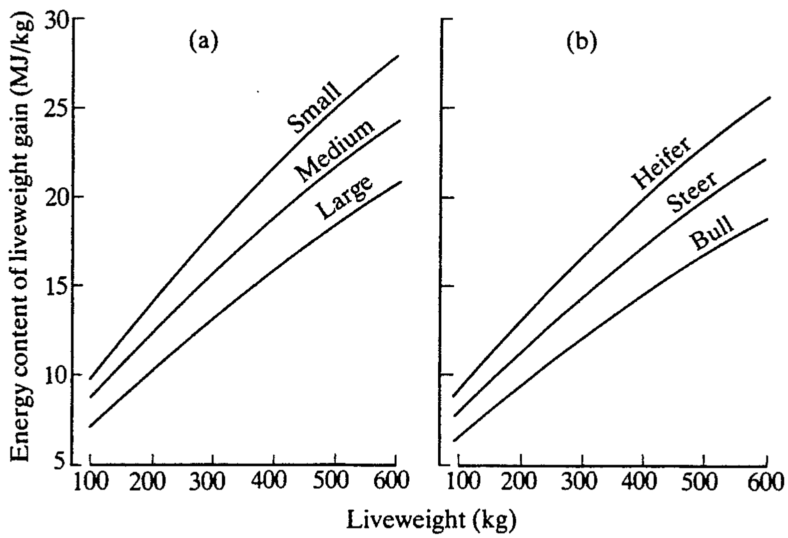


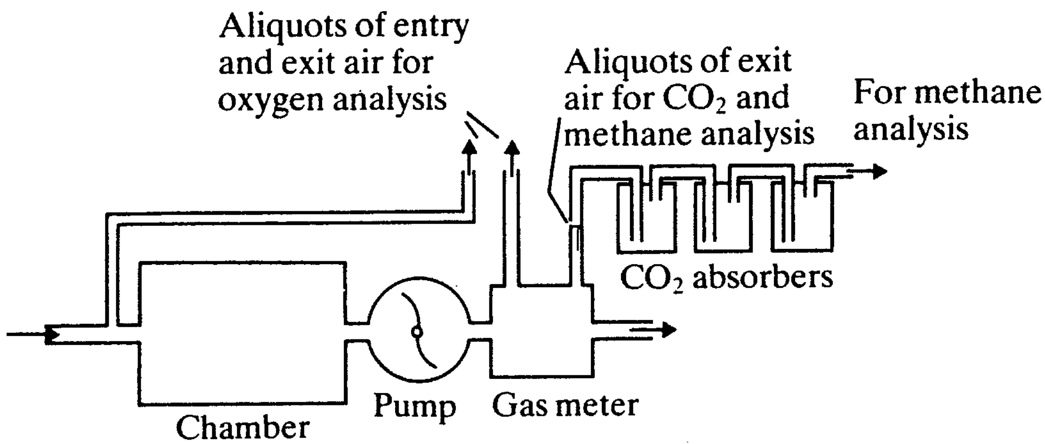
Fig. 14.6 Effects of liveweight, mature size, rate of gain and sex on the energy content of gains made by cattle. (Agricultural Research Council, 1980. *Nutrition Requirements of Ruminant Livestock*. Commonwealth Agricultural Bureaux.) (*a*) Steers of small, medium and large breeds growing at 1.0 kg/day. (*b*) Heifer, steer and bull of a medium-sized breed, all growing at 0.5 kg/day.

TABLE 14.7 A comparison of the indispensable amino acid proportions c tissue proteins of chicks with their dietary requirements for these acids

	Amino acid (g/kg protein)	
	*Tissue proteins**	*Dietary proteins†*
Arginine	67	52
Histidine	20	24
Isoleucine	41	43
Leucine	66	70
Lysine	75	52
Methionine + cystine	35	44
Phenylalanine + tyrosine	64	75
Threonine	40	35
Tryptophan	8	10
Valine	67	50
Glycine	101	63

* H. H. Williams *et al.*, 1954. *J. biol. Chem.*, **208**, 277.
† Calculated for a diet containing 210 g protein/kg from the amino acid requirements in Appendix Table 13.

(*a*) Open circuit



(*b*) Closed circuit

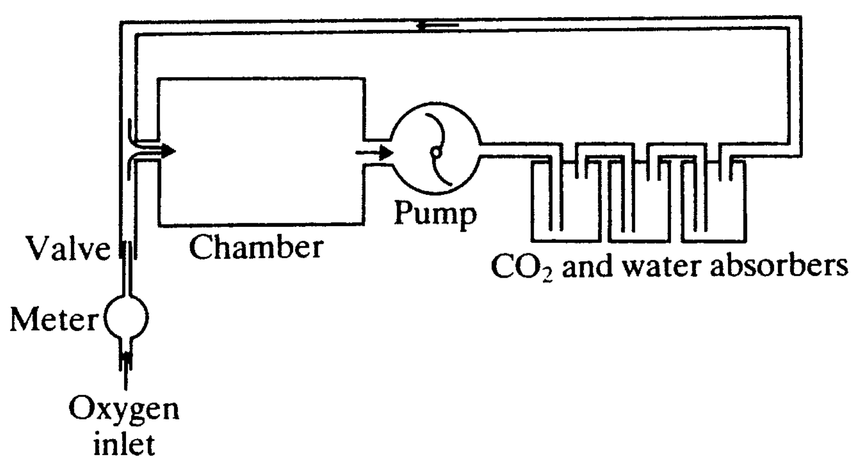
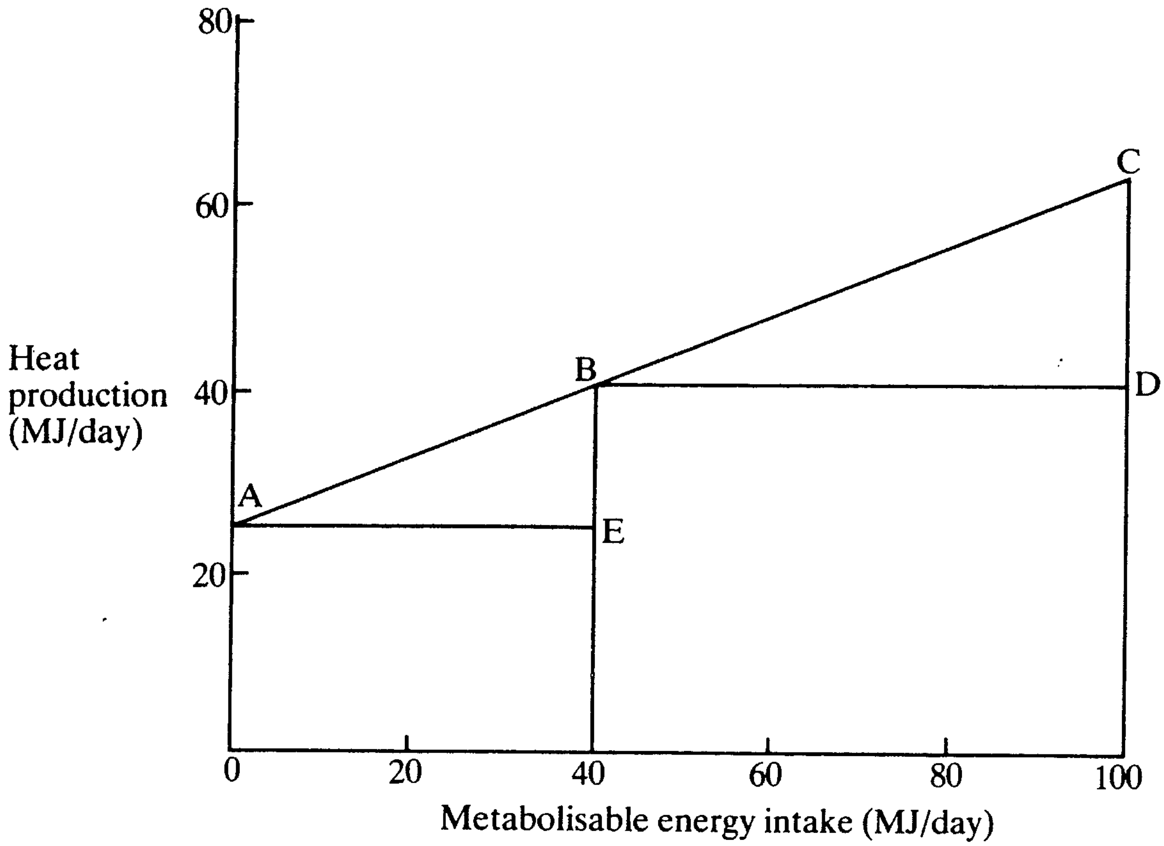


Fig. 11.4. Diagrams of respiration chambers.



80
60
40
20
0
20
40
60
80
100
A
B
C
D
E
Heat production (MJ/day)
Metabolisable energy intake (MJ/day)

TABLE 11.4 Efficiency of utilisation for maintenance of metabolisable energy in various nutrients and foods

	Ruminant	Pig, etc.*	Fowl
Food constituents			
Glucose	0.94 (1.00)†	0.95	0.89
Starch		0.88	0.97
Olive oil		0.97	
Casein	(0.82)	0.76	0.84
Fermentation products			
Acetic acid	0.59		
Propionic acid	0.86		
Butyric acid	0.76		
Mixture A‡	0.87		
Mixture B	0.86		
Concentrates			
Maize	0.80		
Balanced diets			0.81
Roughages			
Dried ryegrass (young)	0.78		
Dried ryegrass (mature)	0.74		
Meadow hay	0.70		
Lucerne hay	0.82		
Grass silage	0.72		

* Including dog and rat
† values in parenthesis are from administration per duodenum.
‡ Mixture A: acetic 0.25, propionic 0.45, butyric 0.30
Mixture B: acetic 0.75, propionic 0.15, butyric 0.10

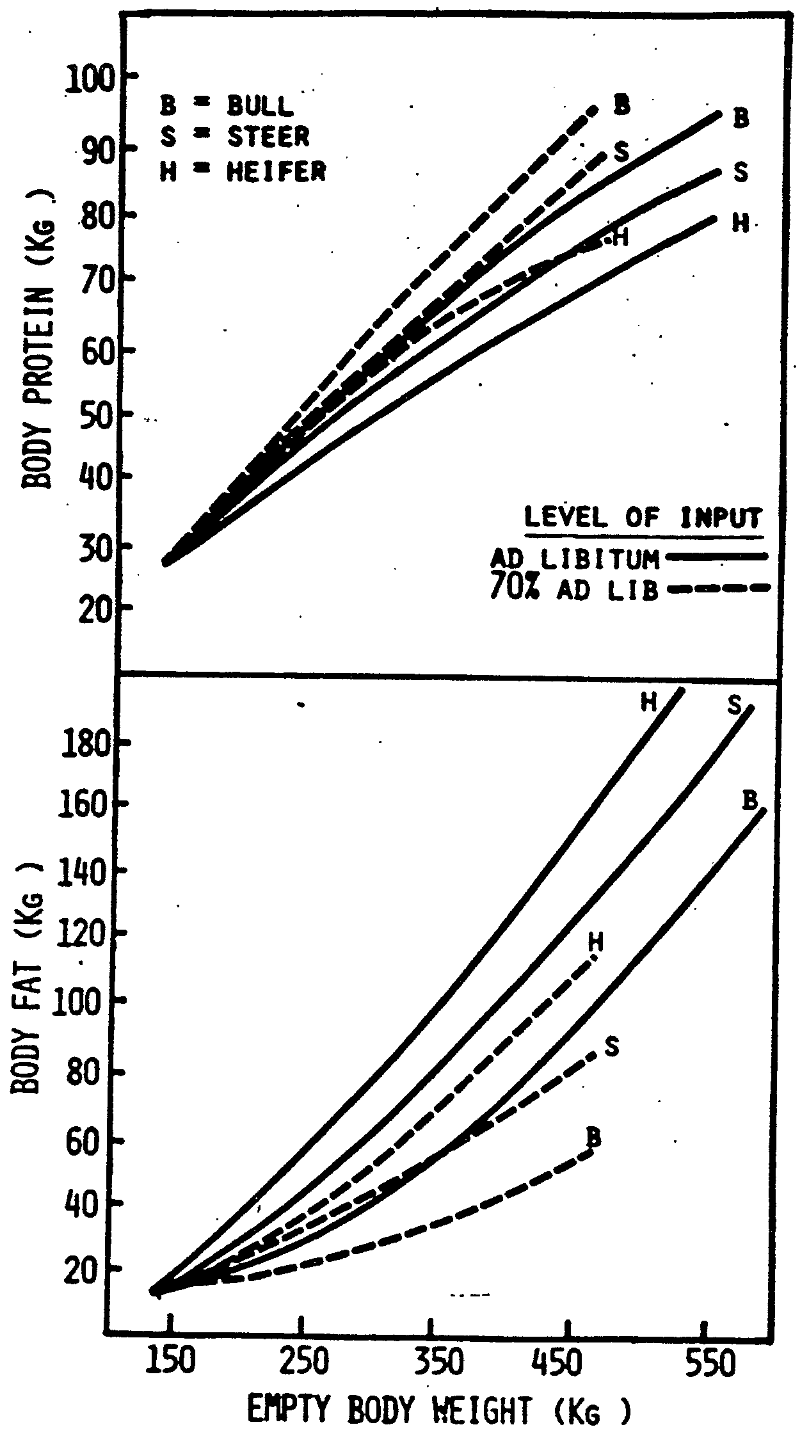
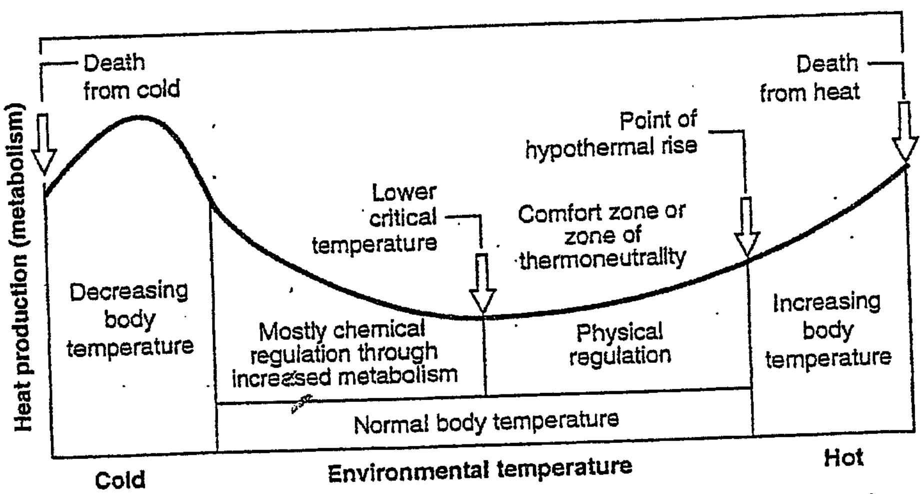
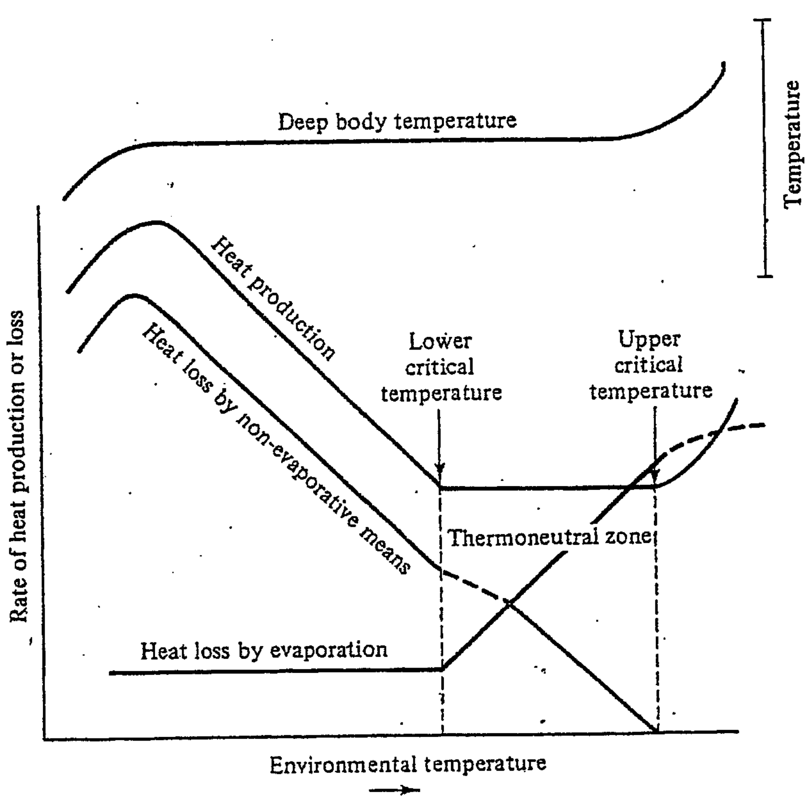


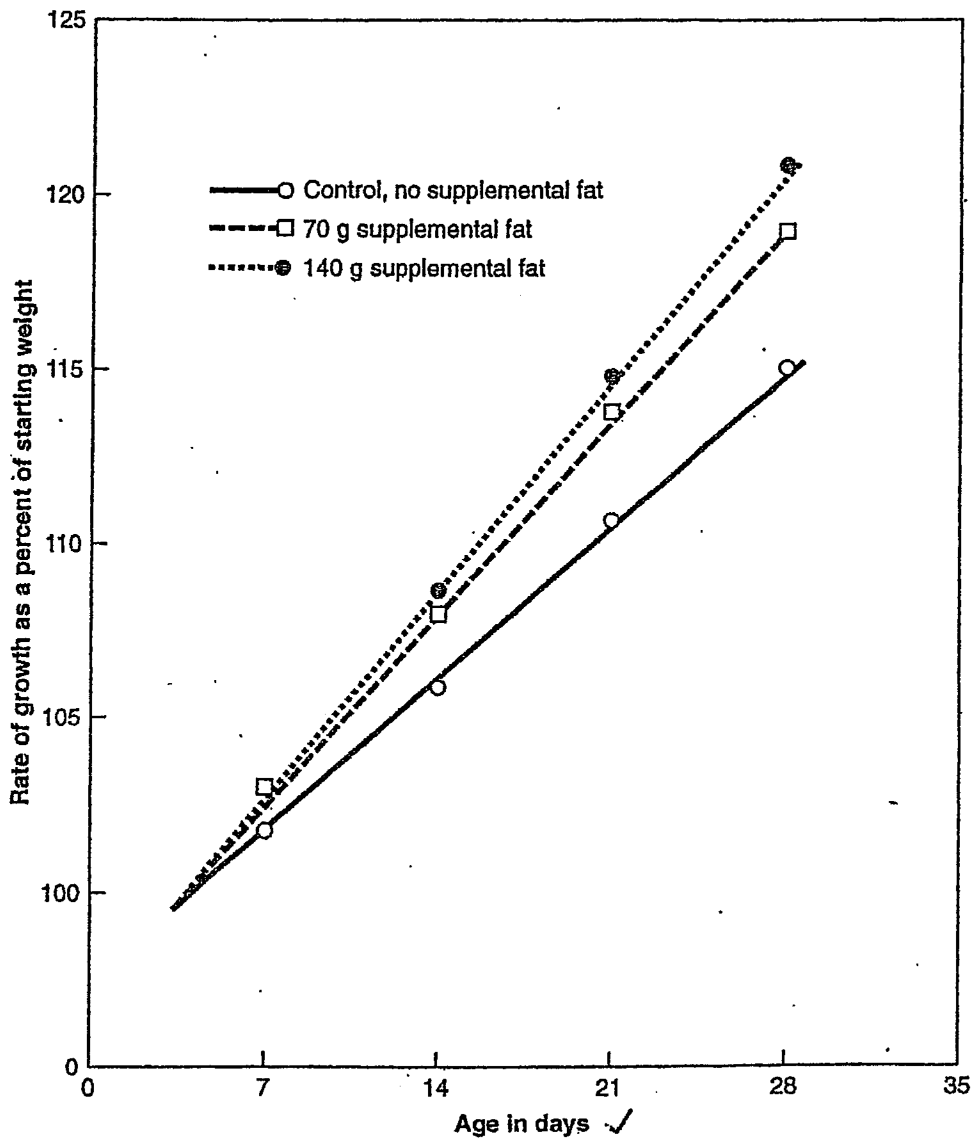
Figure 4. Relationship of sex and level of energy input to the body composition of Holstein cattle.



Physiological and metabolic changes in animals associated with changes in environmental temperature. (Adapted from Brody, 1945)

Fig. 10.7. A diagram of the relation between environmental temperature and heat production in homeothermic animals.





Effect of supplemental fat feeding on growth of young calves during cold weather. (Adapted from Jaster et al., 1990)

Domalski of the US Bureau of Standards (Domalski 1972). They can be regarded as the most accurate values presently available. There is doubt about some of the values central to the methods of estimating heat production by indirect calorimetry. For example, it is not clear whether corrections for pressure changes were made when the enthalpies of combustion of body fats were determined or if the data were corrected to the standard temperature.

Enthalpies of formation can be computed from enthalpies of combustion using a value of -393.51 kJ/mol for the enthalpy of formation of gaseous carbon dioxide, and -285.84 kJ/mol for the enthalpy of formation of liquid water. Methods for calculating enthalpies of formation are given in Chapter 2.

Table A1.1. *Enthalpy of combustion for compounds of biological interest*

Compound	ΔH_c (kJ/mol)
Carbohydrates	
Arabinose (β-D, β-L)	−2338.8
Xylose (α-D)	−2338.9
Galactose (α-D)	−2803.7
Glucose (α-D)	−2803.0
Glucose (β-D)	−2809.3
Fructose (β-D)	−2811.6
Sorbose (L)	−2805.8
Lactose (β)	−5648.4
Maltose	−5645.5
Sucrose	−5640.9
Cellobiose	−5638.4
Raffinose	−8472.6
Glycerol	−1655.4
Starch (MJ/kg)	−17.48
Inulin (MJ/kg)	−17.28
Dextrin (MJ/kg)	−17.20
Glycogen (MJ/kg)	−17.51
Cellulose (MJ/kg)	−17.49
Xylan (MJ/kg)	−17.82
Lignin (MJ/kg)	−27.28
Fatty acids	
Formic	−254.6
Acetic	−874.5
Propionic	−1527
n-Butyric	−2183.5
Pentanoic	−2837.3
Hexanoic	−3491.5
Heptanoic	−4145.5
Decanoic	−6109.1
Undecanoic	−6764
Dodecanoic (lauric)	−7414
Tetradecanoic (myristic)	−8722

Appendix

Table A1.1. (*cont.*)

Compound
Hexadecanoic (palmitic)
Octadecanoic (stearic)
Cis-9-octadecanoic (oleic)
Lipids
Cattle depot fat (MJ/kg)
Human liver and muscle fat (MJ/
Human depot fat (MJ/kg)
Cattle mixed phospholipids (MJ/k
Milk fat (MJ/kg)
Grain lipids (MJ/kg)
Amino acids
Alanine (L)
Arginine (L)
Asparagine (L)
Cysteine (L)
Cystine (L)
Glutamic acid (L)
Glycine
Histidine
Isoleucine (D, L)
Leucine (D, L)
Lysine (DL)
Methionine
Proline (DL)
Phenylalanine (DL, L)
Serine (L)
Threonine (DL, L)
Tyrosine (L)
Valine (DL, L)
Tryptophan
Proteins
Myosin (MJ/kg)
Gelatin (collagens) (MJ/kg)
Mammalian muscle (MJ/kg)
Other compounds
Acetone
Ethanol
Methane
Uric acid
Lactic acid (DL)
Creatine
Creatinine
Urea
Hippuric acid
β-Hydroxy butyric acid (DL)

Note:
*No value traced.

Table A1.1: (*cont.*)

Compound	ΔH_c (kJ/mol)
Hexadecanoic (palmitic)	−10031
Octadecanoic (stearic)	−11339
Cis-9-octadecanoic (oleic)	−11194
Lipids	
Cattle depot fat (MJ/kg)	−39.3
Human liver and muscle fat (MJ/kg)	−39.4
Human depot fat (MJ/kg)	−39.8
Cattle mixed phospholipids (MJ/kg)	−34.0
Milk fat (MJ/kg)	−38.7
Grain lipids (MJ/kg)	−38.9
Amino acids	
Alanine (L)	−1620.5
Arginine (L)	−3739.9
Asparagine (L)	−1928.7
Cysteine (L)	−2261.5
Cystine (L)	−4252.2
Glutamic acid (L)	−2243.5
Glycine	−973.5
Histidine	*
Isoleucine (D, L)	−3583.6
Leucine (D, L)	−3583.1
Lysine (DL)	−3683.2
Methionine	−3386.9
Proline (DL)	−2728
Phenylalanine (DL, L)	−4645.5
Serine (L)	−1454.8
Threonine (DL, L)	−2102.2
Tyrosine (L)	−4430.0
Valine (DL, L)	−2919.6
Tryptophan	−5628.3
Proteins	
Myosin (MJ/kg)	−24.89
Gelatin (collagens) (MJ/kg)	−22.05
Mammalian muscle (MJ/kg)	−23.70
Other compounds	
Acetone	−1790.4
Ethanol	−1366.8
Methane	−890.3
Uric acid	−1921.1
Lactic acid (DL)	−1367.3
Creatine	−2324.0
Creatinine	−2336.9
Urea	−631.8
Hippuric acid	−4218.5
β-Hydroxy butyric acid (DL)	−2038.4

Note:
*No value traced.

Analysis of the Oxidation of Mixtures of Carbohydrates and Fat

Non-protein respiratory quotient	Caloric value of 1 liter oxygen	Caloric value of 1 liter of CO_2	Percentage of total O_2 consumed by fat	Percentage of total heat produced by fat
.707	4.686	6.629	100.0	100.0
.71	4.690	6.606	99.0	98.9
.72	4.702	6.531	95.6	95.2
.73	4.714	6.458	92.2	91.6
.74	4.727	6.388	88.7	88.0
.75	4.739	6.319	85.3	84.4
.76	4.751	6.253	81.9	80.8
.77	4.764	6.187	78.5	77.2
.78	4.776	6.123	75.1	73.7
.79	4.788	6.062	71.7	70.1
.80	4.801	6.001	68.3	66.6
.81	4.813	5.942	64.8	63.1
.82	4.825	5.884	61.4	59.7
.83	4.838	5.829	58.0	56.2
.84	4.850	5.774	54.6	52.8
.85	4.862	5.721	51.2	49.3
.86	4.875	5.669	47.8	45.9
.87	4.887	5.617	44.4	42.5
.88	4.899	5.568	41.0	39.2
.89	4.911	5.519	37.5	35.8
.90	4.924	5.471	34.1	32.5
.91	4.936	5.424	30.7	29.2
.92	4.948	5.378	27.3	25.9
.93	4.961	5.333	23.9	22.6
.94	4.973	5.290	20.5	19.3
.95	4.985	5.247	17.1	16.0
.96	4.998	5.205	13.7	12.8
.97	5.010	5.165	10.2	9.51
.98	5.022	5.124	6.83	6.37
.99	5.035	5.085	3.41	3.18
1.00	5.047	5.047	0	0

Kreyewicki and Consolozio (1968)

Hospital Data

TABLE 3 Body Density and Percentage of Fat in Adult Males, Fitzsimons General Hospital

Age Group	n	Body Weight (kg)	Density (g/ml)	Fat (%)
17–19	9	71.9 ± 14.4	1.060 ± 0.016	19.6 ± 7.0
20–24	35	73.6 ± 7.5	1.060 ± 0.013	19.5 ± 5.5
25–29	29	76.8 ± 14.0	1.053 ± 0.017	22.6 ± 7.3
30–34	15	85.8 ± 17.6	1.044 ± 0.013	26.3 ± 6.1
35–39	13	76.2 ± 10.6	1.043 ± 0.012	26.9 ± 3.6
40–44	25	75.4 ± 11.1	1.042 ± 0.012	27.1 ± 5.5
45–49	24	76.2 ± 10.0	1.038 ± 0.010	29.3 ± 4.5
50–54	12	75.5 ± 10.1	1.032 ± 0.026	32.8 ± 9.1
55–59	4	79.0 ± 10.3	1.031 ± 0.021	32.5 ± 4.8
60–64	5	69.7 ± 7.5	1.026 ± 0.010	34.7 ± 4.5
65–69	2	68.6 ± 2.1	1.017 ± 0.001	38.7 ± 0.6
TOTAL	173			

V. Sex effects

1. In general males tend to have a lower body fat then females of the same species. We have reviewed data for beef cattle already. Reid et al., 1981.

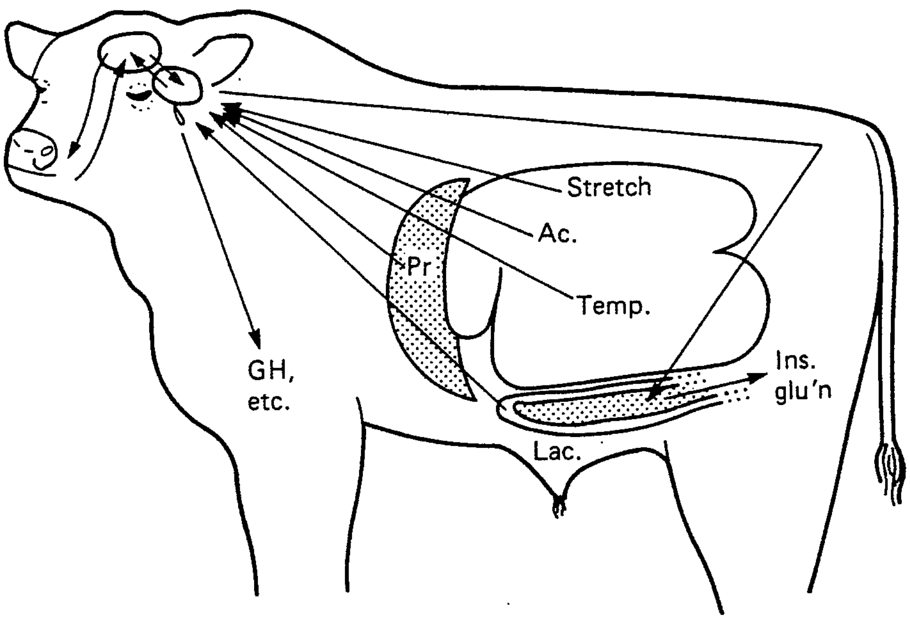


Figure 2.1 Diagram of some of the pathways thought to be involved in the control of food intake (Ac, acetate; GH, growth hormone; glu'n, glucagon; Ins., insulin; Lac, lactate) (From Forbes, 1980; reproduced with permission)

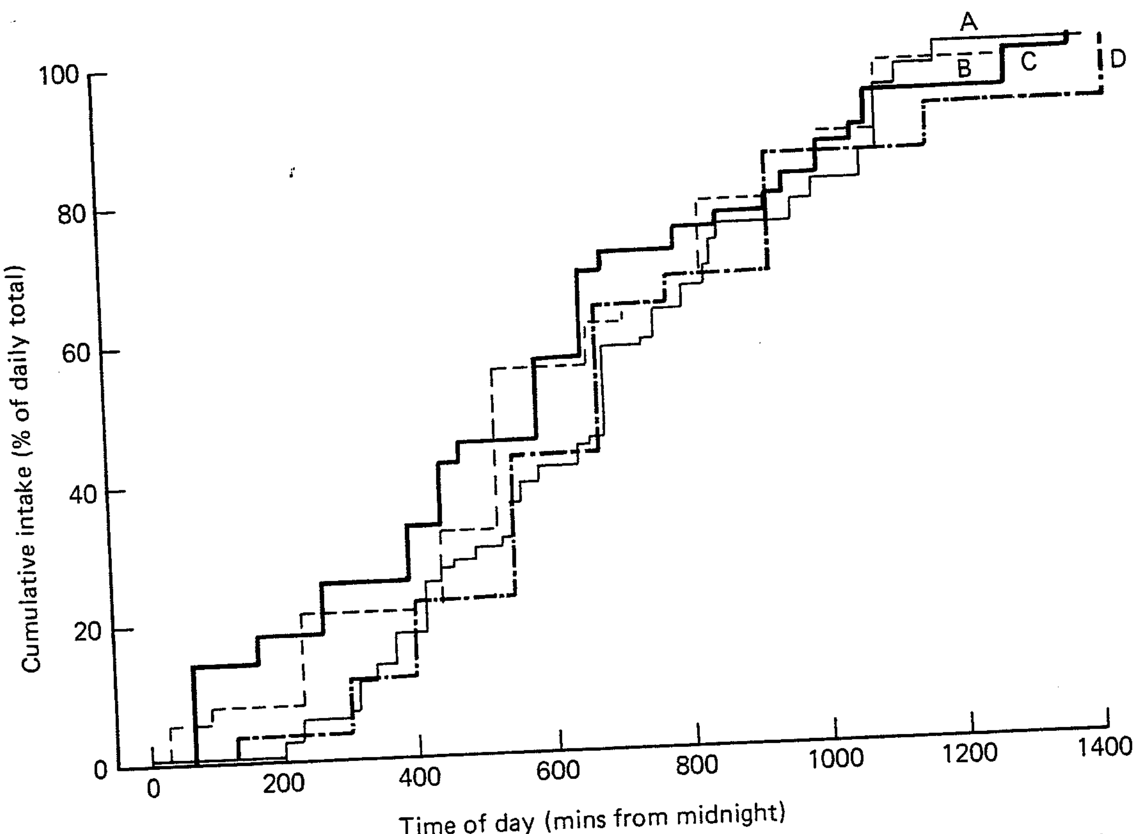


Figure 1.2 Meal patterns of a chicken, sheep, cow and pig (unpublished observations). Note the smaller, less frequent meals at night (A, chicken, 31 meals; B, sheep, 14 meals; C, cow, 18 meals; D, pig, 9 meals)

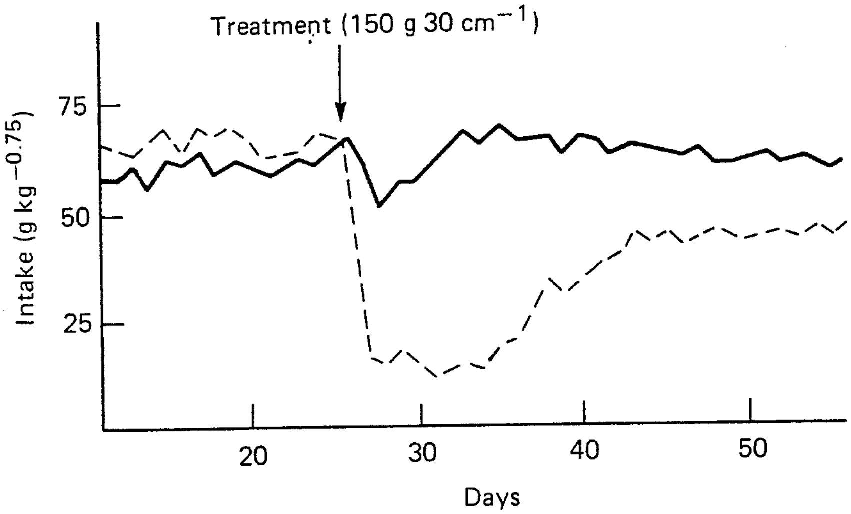


Figure 2.3 Daily intake of hay by sheep with or without the addition of 150 g of polypropylene fibres to the rumen on day 26 (After Welch, 1967)

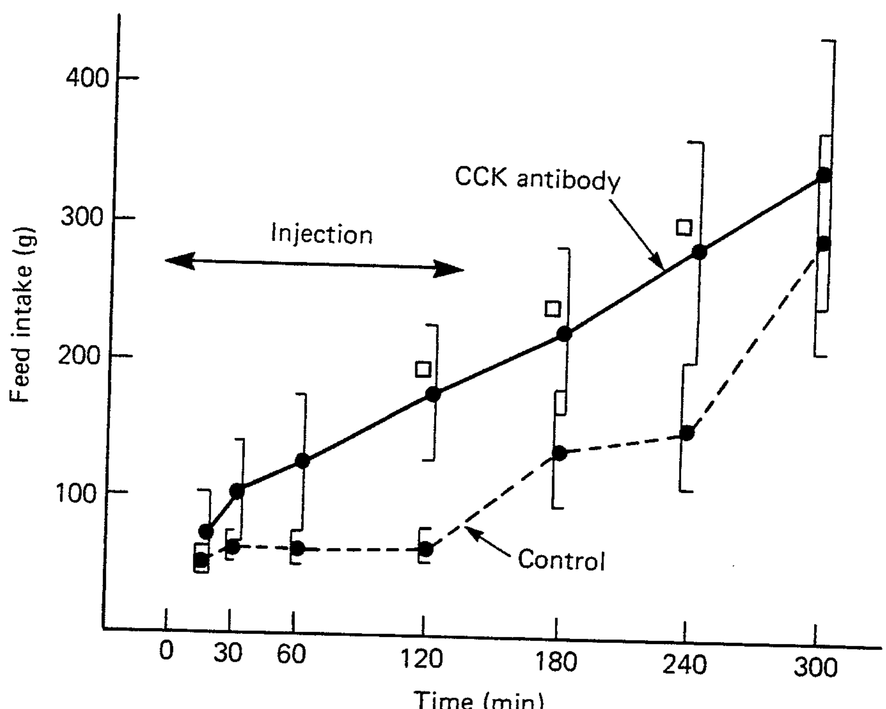


Figure 4.8 Increased intake of food by sheep injected into the lateral ventricle with CCK antibody (From Della-Fera and Baile, 1981; reproduced with permission)

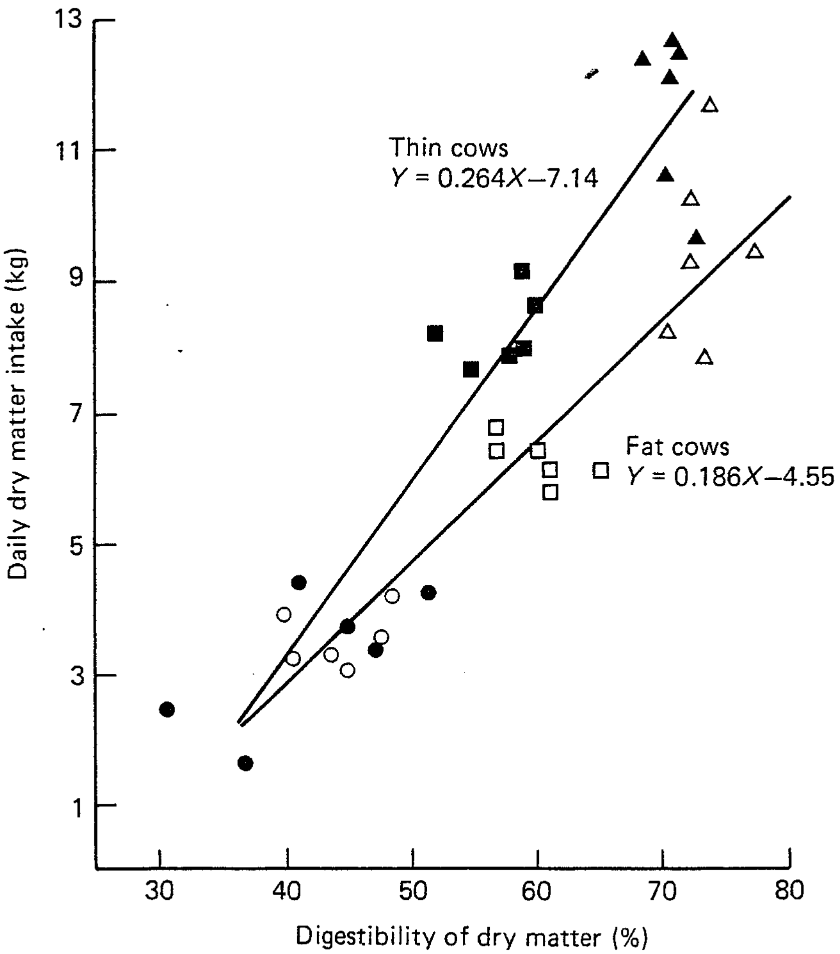


Figure 5.6 Relationship between voluntary intake and digestibility of the diet in fat (open symbols) and thin (solid symbols) cows (○, ●, straw; □, ■, hay; △, ▲, concentrates) (From Bines *et al.*, 1969; reproduced with permission)

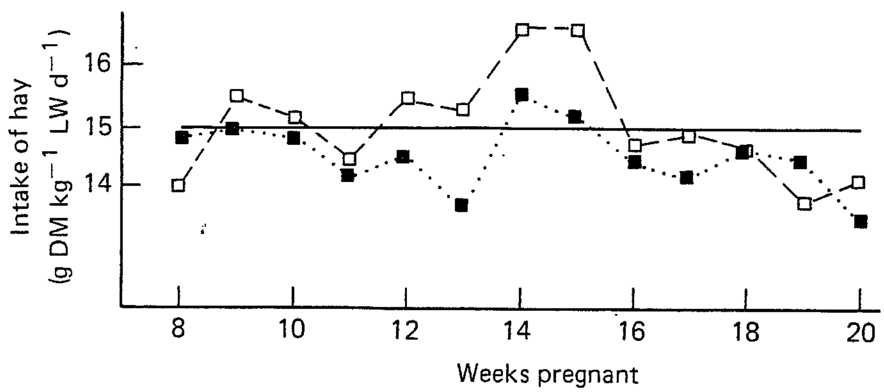


Figure 5.8 Changes in hay intake during the latter half of pregnancy in ewes carrying single (open symbols) or twin (closed symbols) foetuses, corrected for variations in intake by non-pregnant ewes (horizontal line) (From Forbes, 1968a; reproduced with permission)

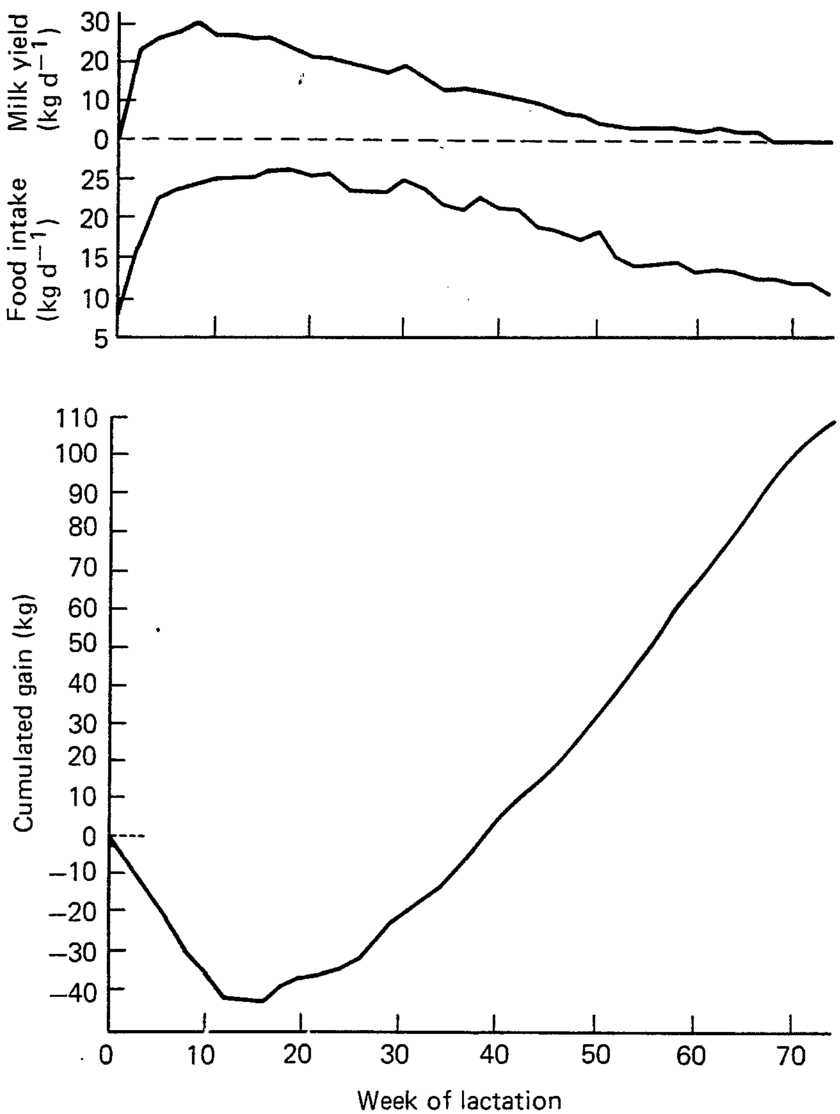


Figure 5.10 Changes in milk yield, intake of a complete feed and body weight gain in Friesian cows (After Monteiro, 1972)

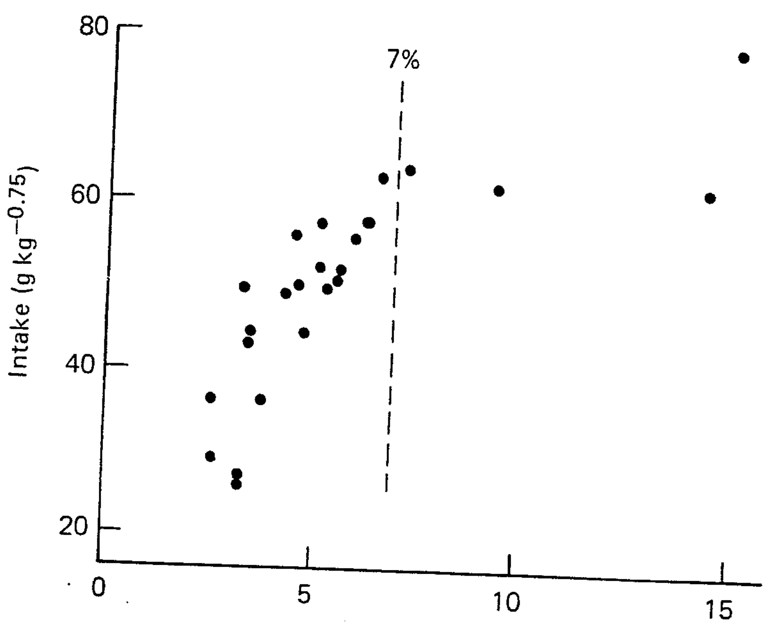


Figure 6.7 Relationship between the crude protein content of tropical forages and intake by sheep (After Milford and Minson, 1966)

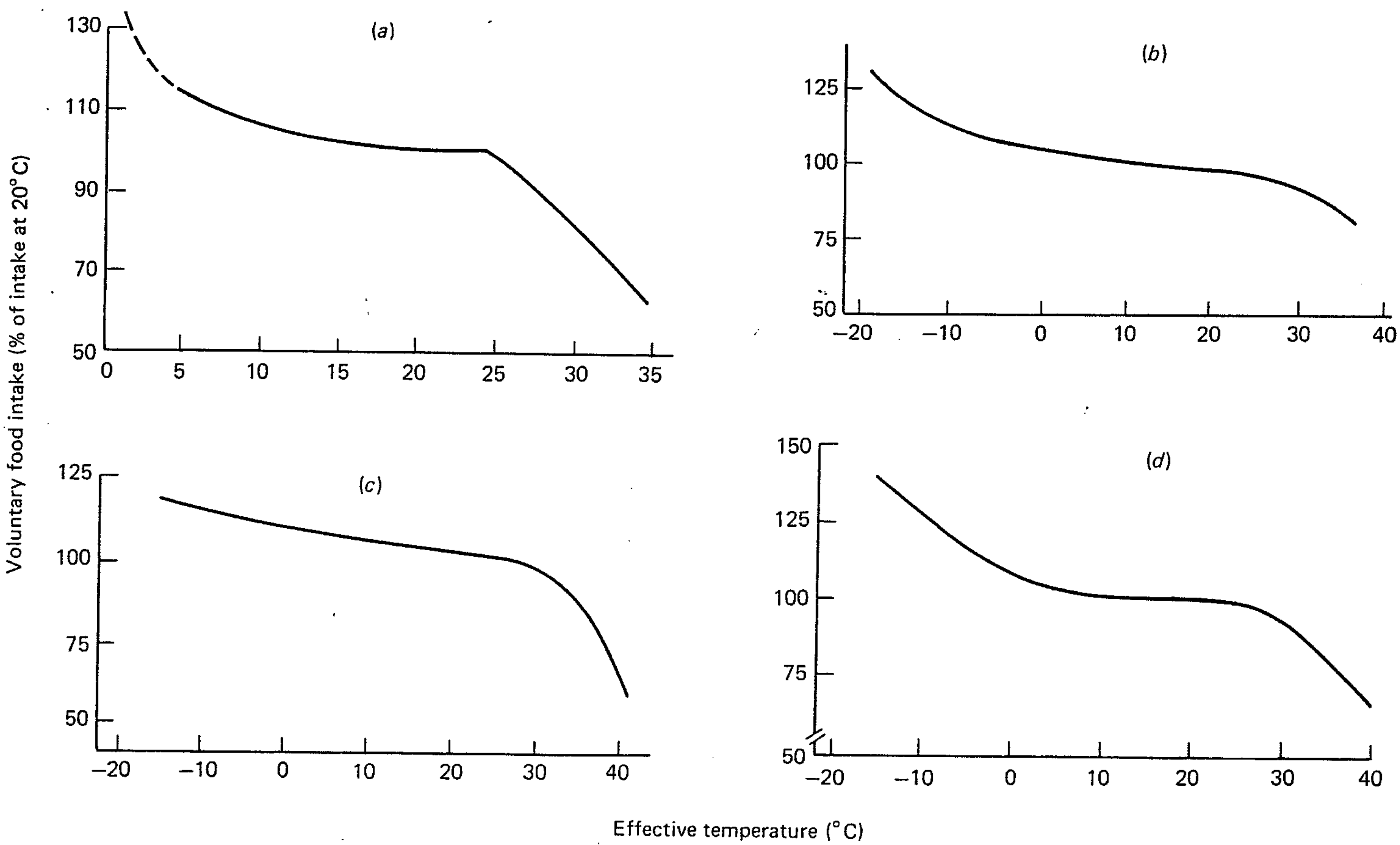


Figure 7.1 Food intake responses of poultry, pigs and cattle to different ambient temperatures: (a) laying hens; (b) growing pigs; (c) growing cattle; (d) dairy cows (After NRC, 1981)

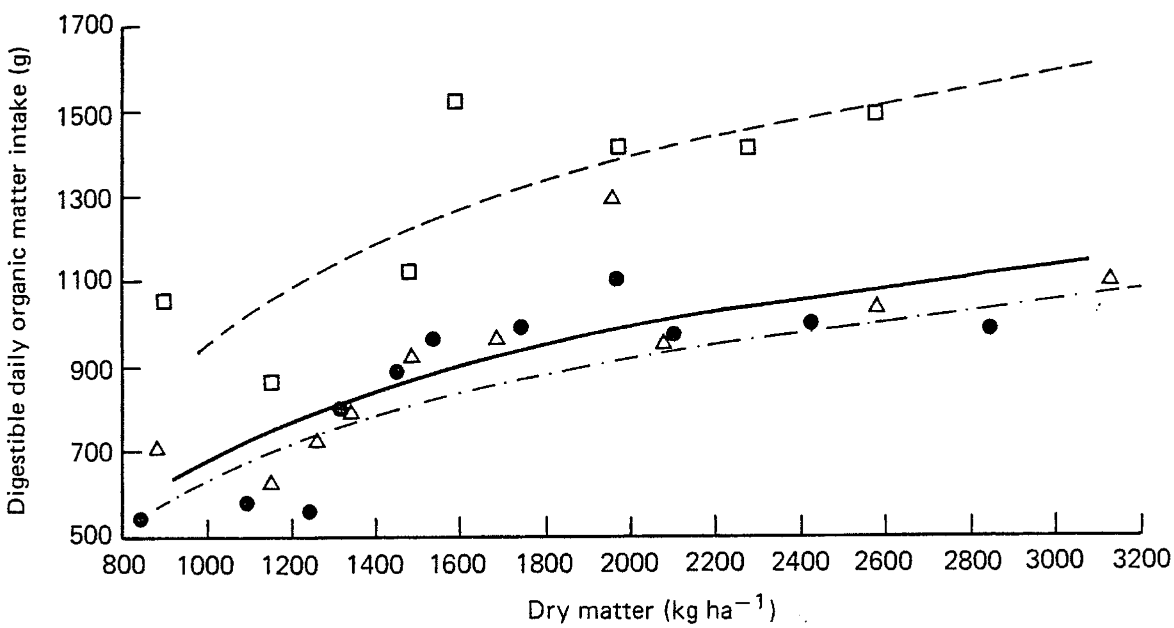


Figure 8.5 Effect of herbage allowance and physiological state of ewes on their herbage intake (△ — △, pregnant (1); □ – – – □, lactating (2); ● – · – · – ●, control) (From Arnold and Dudzinski, 1967; reproduced with permission)

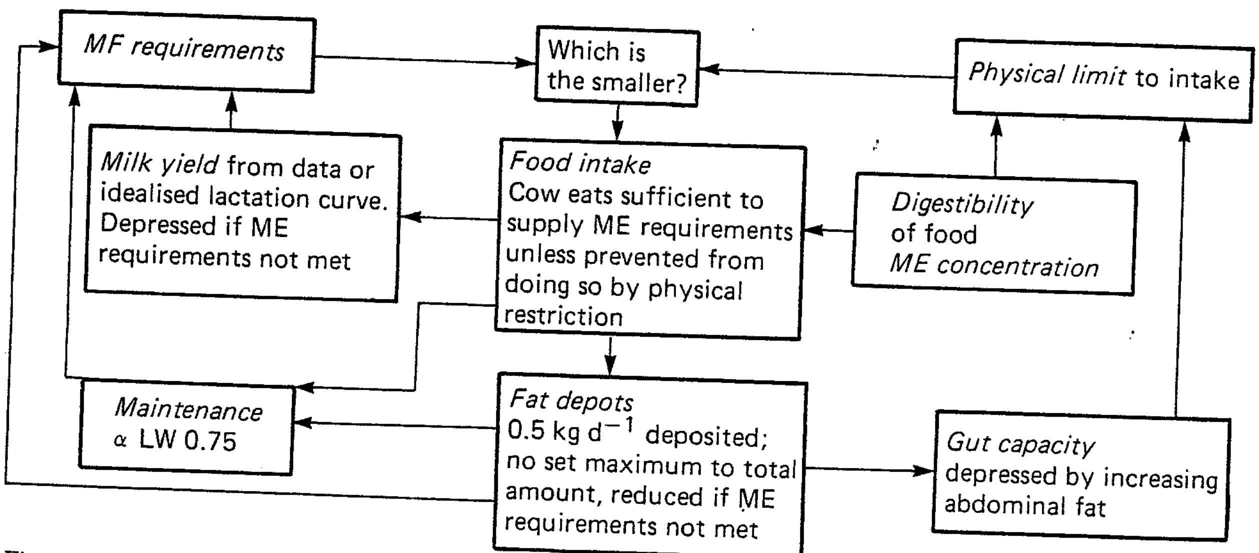


Figure 9.3 Flow diagram of a model of food intake in lactating cows (From Forbes, 1983, after Forbes, 1977b; reproduced with permission of Elsevier Science Publishers BV)

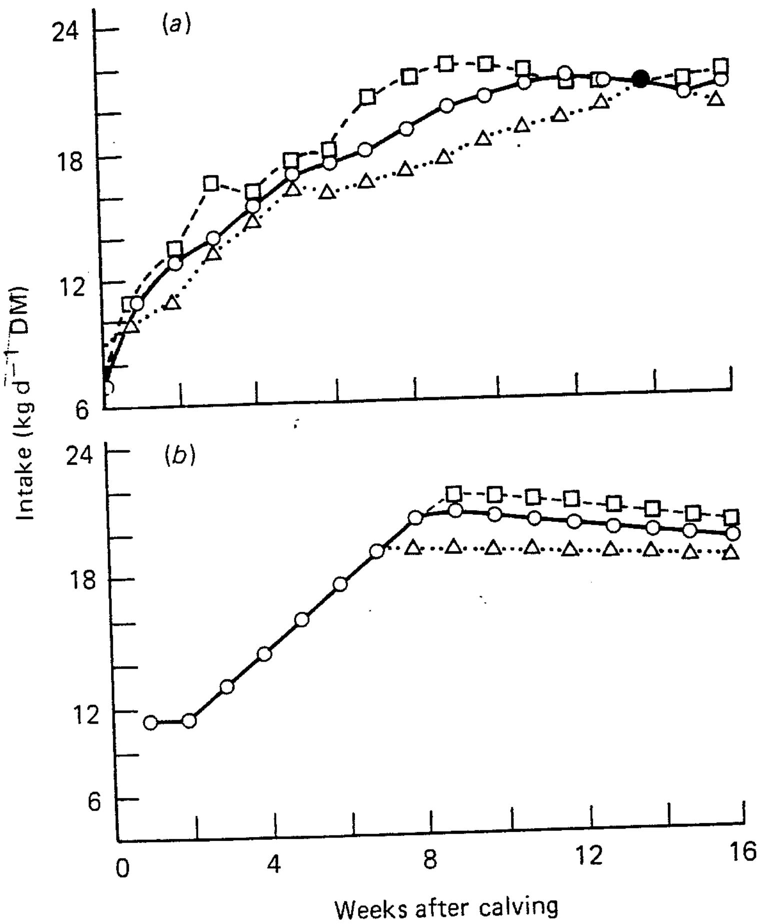


Figure 9.4 (a) Observed intakes of cows that were fat (△), medium (○) and thin (□) at calving (From Garnsworthy and Topps, 1982; (b) Predictions of a cow model (From Forbes, 1983; reproduced with permission of Elsevier Science Publishers BV)

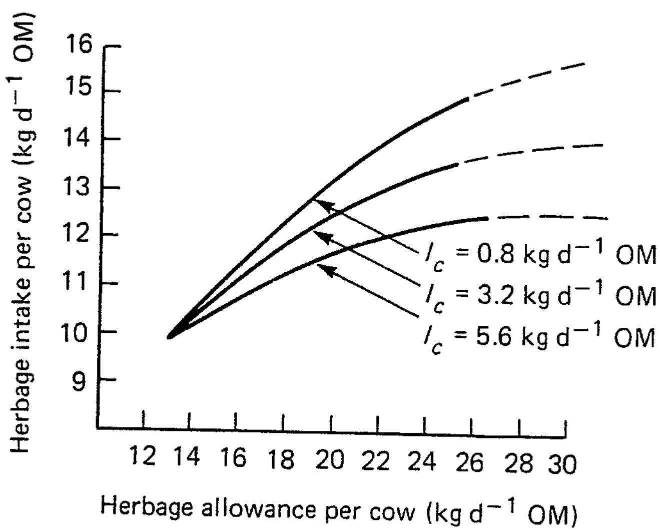


Figure 10.3 Herbage intake by cows at a range of herbage allowances and three levels of supplementation (From Meijs and Hoekstra, 1984; reproduced with permission of Blackwell Scientific Publications Ltd)

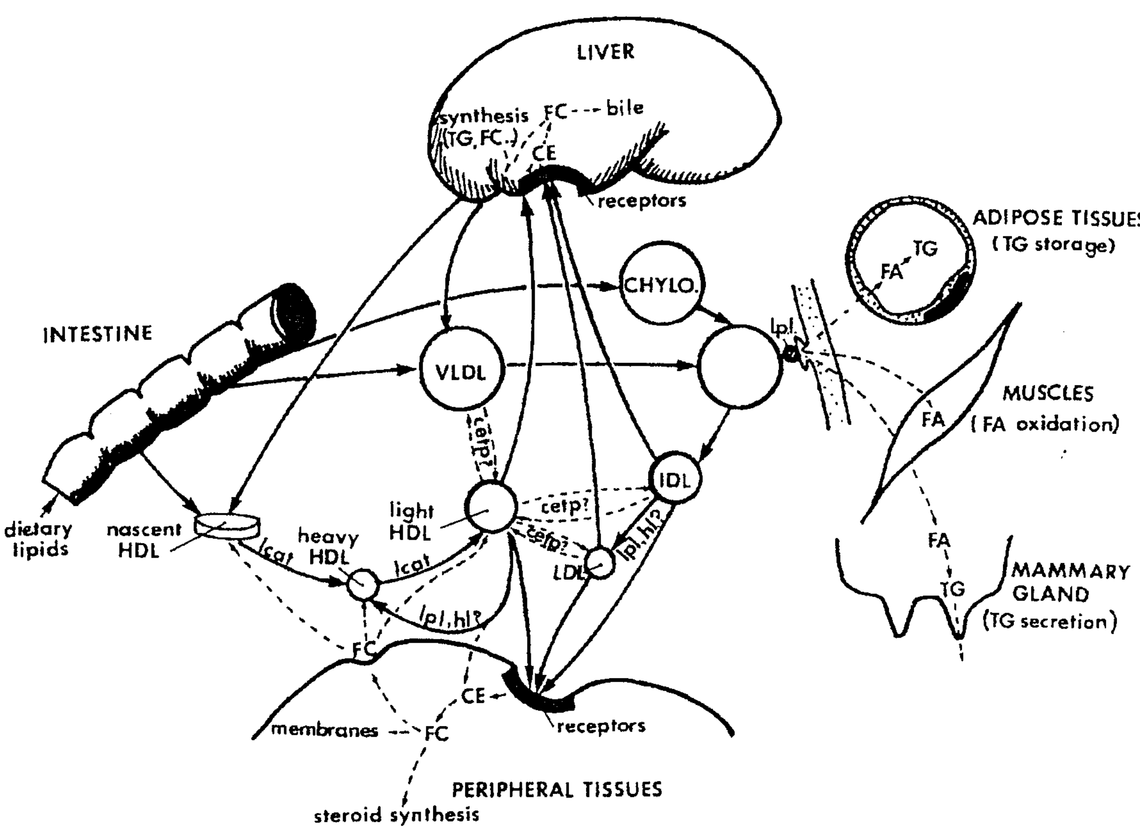
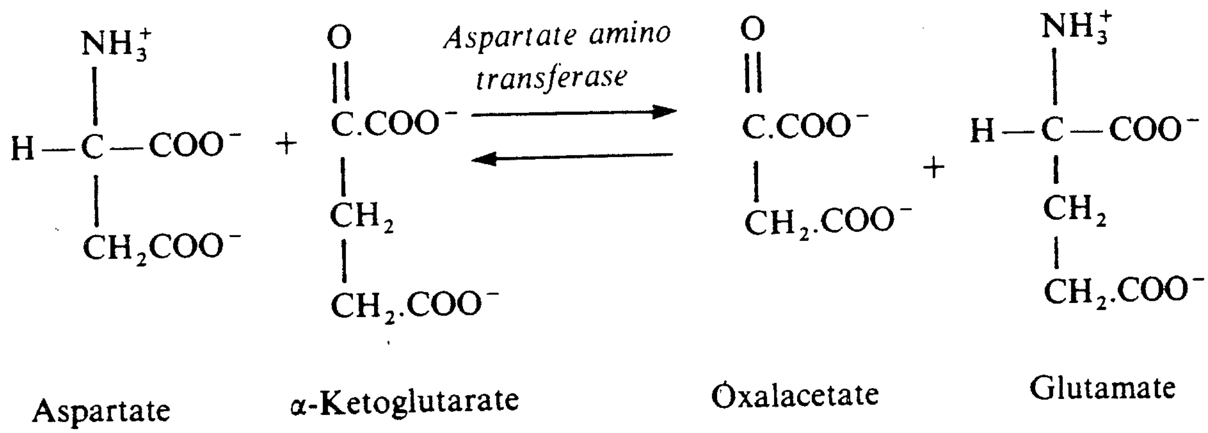
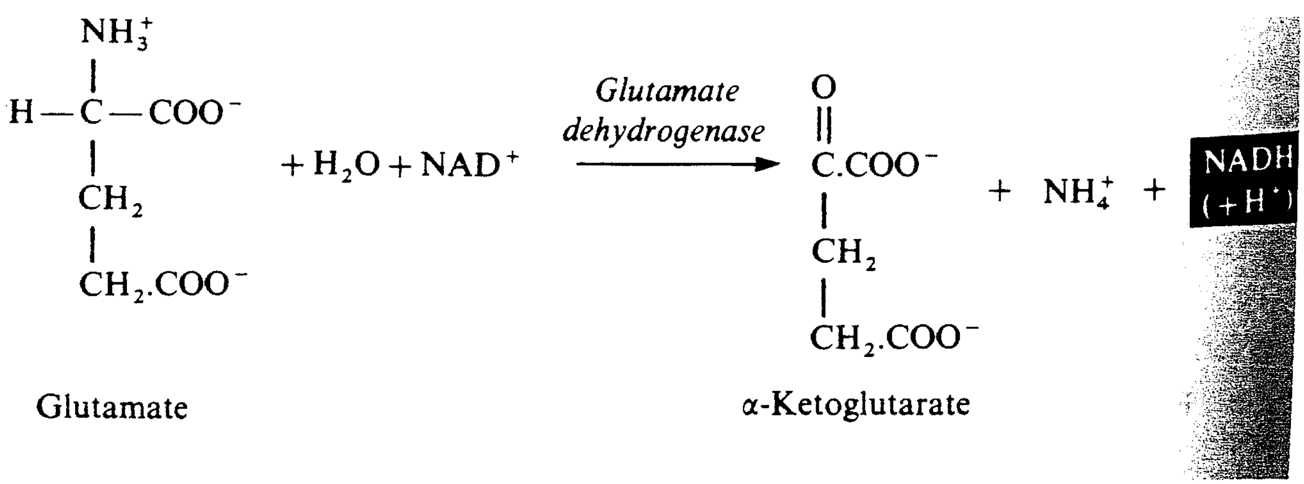
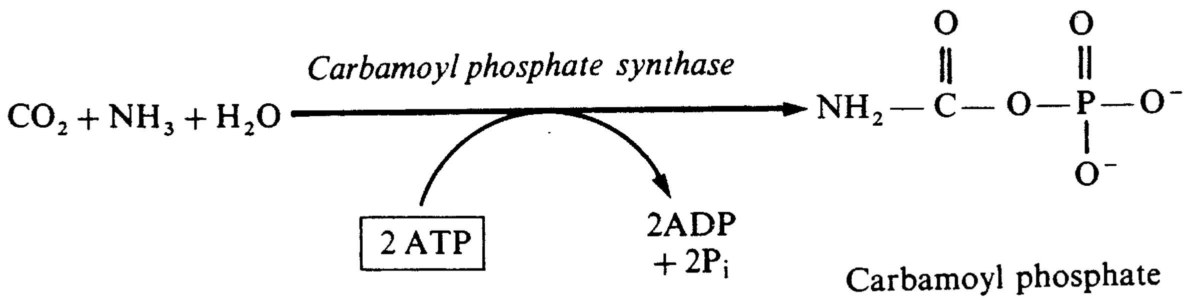
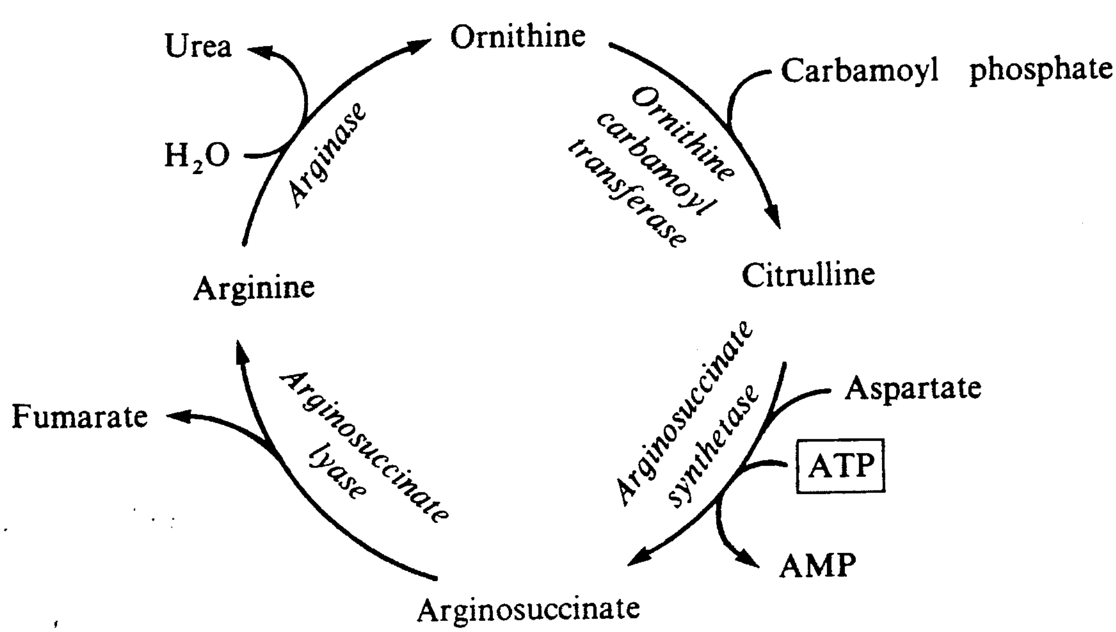


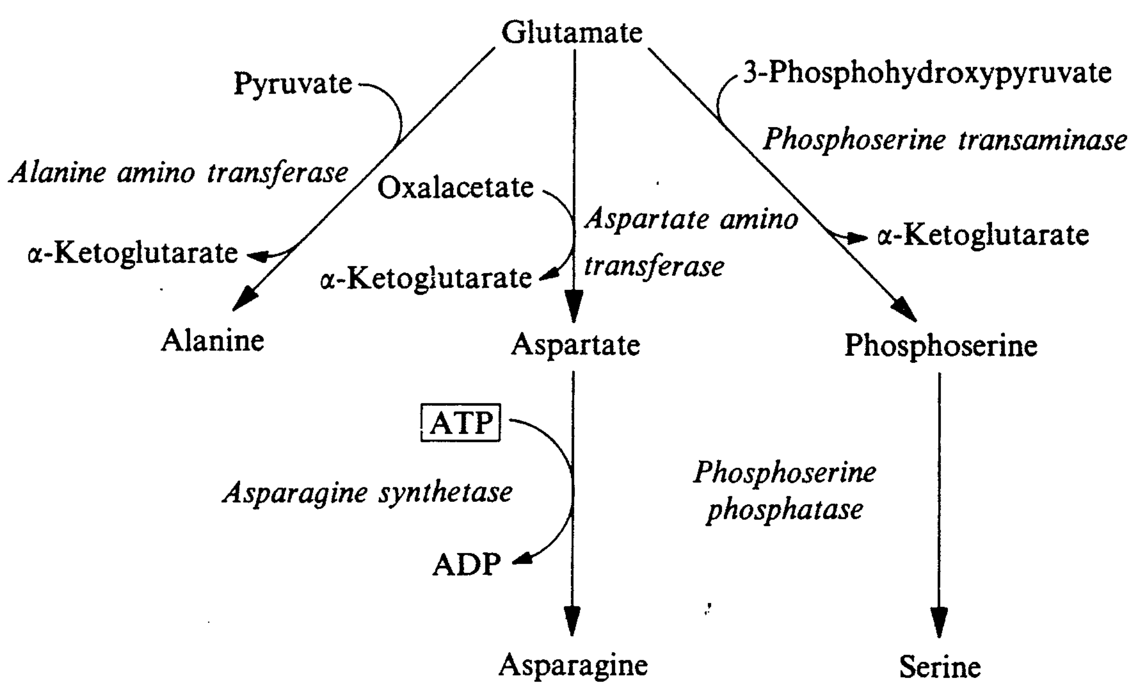
Figure 1. The tissue origins and postsecretory metabolic transformation of lipoproteins within the plasma compartment in ruminants. HDL = High density lipoproteins, LDL = low density lipoproteins, TG = triglyceride, CE = cholesterol ester, cetp = CE transfer protein, lcat = lecithin:cholesterol acyltransferase, CHYLO = chylomicron, VLDL = very low density lipoproteins, lpl = lipoprotein lipase, hl = hepatic lipase, FA = fatty acid, FC = free cholesterol.

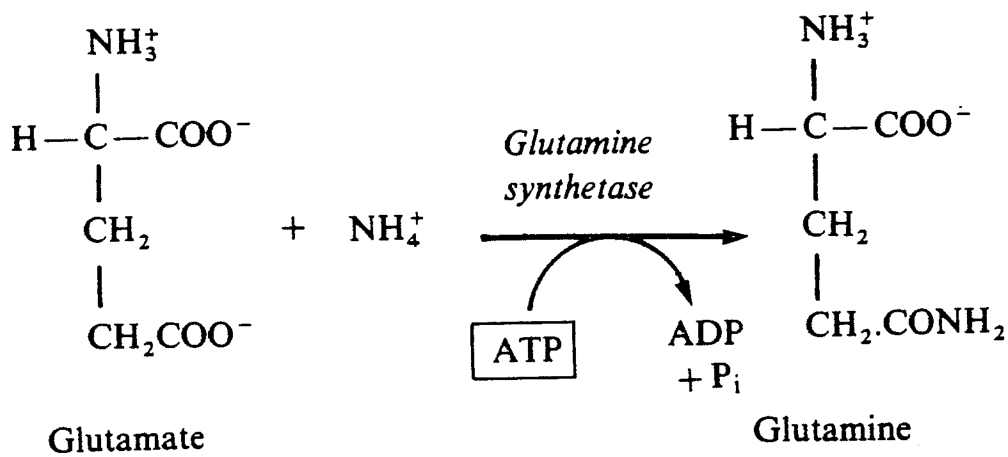

Aspartate amino
transferase
Aspartate
α-Ketoglutarate
Oxalacetate
Glutamate

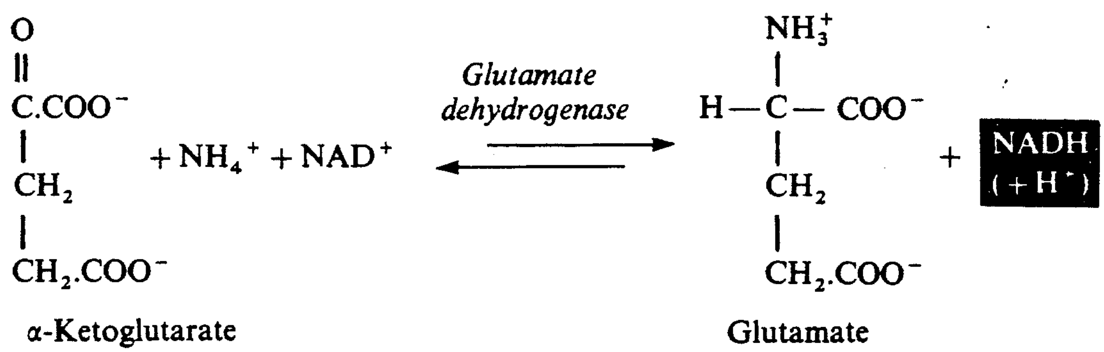

Glutamate
dehydrogenase
NADH
(+H⁺)
Glutamate
α-Ketoglutarate

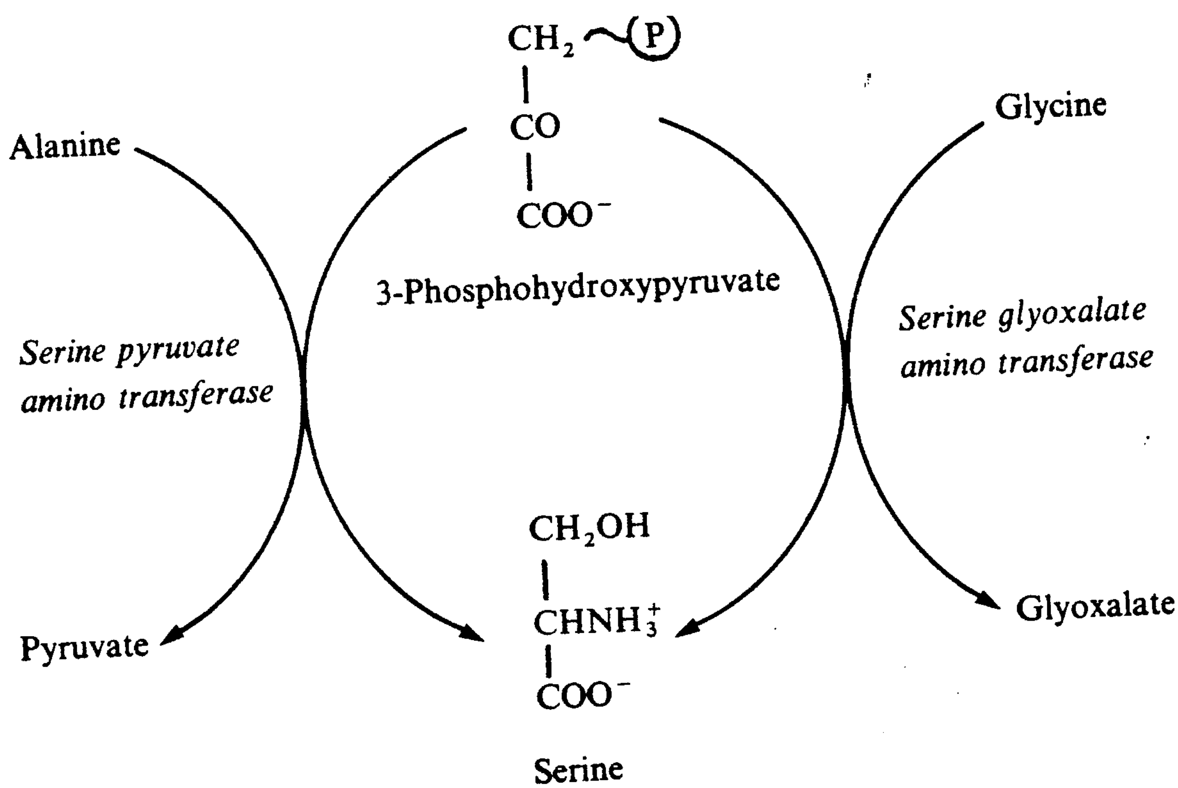

Carbamoyl phosphate synthase
CO2 + NH3 + H2O
2 ATP
2ADP
+ 2Pi
NH2 — C — O — P — O−
Carbamoyl phosphate


Ornithine
Urea
H2O
Arginase
Carbamoyl phosphate
Ornithine carbamoyl transferase
Citrulline
Arginine
Fumarate
Argininosuccinate lyase
Argininosuccinate synthetase
Aspartate
ATP
AMP
Arginosuccinate


Glutamate
Pyruvate
3-Phosphohydroxypyruvate
Phosphoserine transaminase
Alanine amino transferase
Oxalacetate
Aspartate amino
transferase
α-Ketoglutarate
α-Ketoglutarate
α-Ketoglutarate
Alanine
Aspartate
Phosphoserine
ATP
Asparagine synthetase
Phosphoserine
phosphatase
ADP
Asparagine
Serine


Glutamine synthetase
ATP
ADP + P_i
Glutamate
Glutamine


Glutamate dehydrogenase
$+ NH_4^+ + NAD^+$
NADH ($+H^+$)
α-Ketoglutarate
Glutamate


CH2 ~(P)
CO
COO−
3-Phosphohydroxypyruvate
Alanine
Pyruvate
Serine pyruvate amino transferase
Glycine
Glyoxalate
Serine glyoxalate amino transferase
CH2OH
CHNH3+
COO−
Serine