Chem 352 – Lecture 10 Lipid, Amino Acid, and Nucleotide Metabolism Part I: Lipid Metabolism

Introduction

In Lecture 10 we will add some of the peripheral pathways in metabolism that lead to synthesis and degradation three important classes of biomolecules:

- Lipids
- Amino acids
- Nucleotides

Chem 352, Lecture 10, Part I: Lipid Metabolism 2

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| In        | Other<br>carbohydrates               | Starch<br>"Glycogen                                      | he       |
|-----------|--------------------------------------|--|----------|
| per       | Pentose phosphate pathway (12.5) Glo | Starch synthesis (15.5) Lig<br>Glycogen synthesis (12.5) |          |
| tha       | / /                                  | Calvin cycle (15.4) CO <sub>2</sub> Photosynthesis       | on       |
| thr       | DNA                                  | ATP ADI  | P + Pi   |
| biopna (2 | RNA Ribose,                          | Gluconeogenesis NADPH NAI                                | OP+ + H+ |
| , RNA (2  | Nucleotide Pyr                       | ruvate Fatty acid<br>synthesis (16)<br>(16.1) Fatty      |          |
| • 6       | Amino ← Acet                         | ryl CoA acids Lipic                                      | ls       |
| • 1       | pat (13.                             | roxylate<br>thway<br>(.7) Membro                         | ines     |
|           | athways Citr                         | ic acid synthesis (17) synthesis                         |          |
|           | (                                    | Amino Pr<br>acids<br>Nitrogen                            | oteins   |

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#### Introduction

In Lecture 10 we will add some of the peripheral pathways in metabolism that lead to synthesis and degradation three important classes of biomolecules:

#### • Lipids

- Amino acids
- Nucleotides

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#### Introduction

In Lecture 10 we will add some of the peripheral pathways in metabolism that lead to synthesis and degradation three important classes of biomolecules:

- Lipids
- Amino acids
- Nucleotides

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#### Introduction

Lipids play many important cellular roles

- Membrane components (phospholipids, et al. and cholesterol)
- Fuels (Triacylglycerides)
- Meet long term energy needs in mammals
- Regulators (steroids, eicosanoids)

We will focus on just a couple of key metabolic pathways.

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#### Introduction

We will focus on the following sections from Chapter 16

- 16.1: Fatty Acid Synthesis
- 16.6: Synthesis of Cholesterol
- 16.7: Fatty Acid Oxidation
- 16.9: Lipid Metabolism is Regulated by Hormones in Mammals
- 16.10: Absorption and Mobilization of Fuel Lipids in Mammals
- 16.11: Ketone Bodies Are Fuel Molecules

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## Fatty Acid Synthesis

Fatty acids are synthesized by the repetitive addition of 2 carbon units to a growing chain.

- Acetyl-CoA is the source of the 2 carbon units.
- The Acetyl groups are activated by carboxylating them to Malonyl groups

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#### 5-1

#### Fatty Acid Synthesis

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5-2

## Fatty Acid Synthesis

5-3

| н | Fatty Acids  Fatty acids  Mechanism is similar to that for pyruvate carboxylase | ore sv     |                      | Dv the  Oxaloacetat  coo  c=0  H®  cH2  coo | e A         |
|---|---|------------|----------------------|---|-------------|
|   | O + HN1 NH Bicarbonate Biotin   | ATP        | © Carboxybiotin      | H!<br>nz                                    | NH<br>S Enz |
|   |   | o<br>⊝o Ma | CH <sub>2</sub> —COO | e 10, Part I: Lipid Mete                    | abolism 5   |

| Fatty Acid Synth | esis |
|------------------|------|
|------------------|------|

Fatty acids are synthesized by the repetitive addition of 2 carbon units to a growing chain.

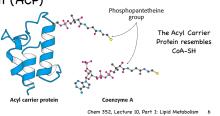
- Acetyl-CoA is the source of the 2 carbon units.
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#### Fatty Acid Synthesis

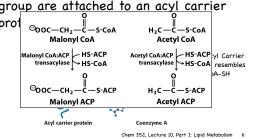
In eukaryotes, both the growing chain, the acetyl group, and the malonyl group are attached to an acyl carrier protein (ACP)



6-1

## Fatty Acid Synthesis

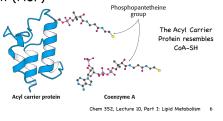
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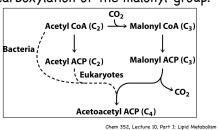


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# Fatty Acid Synthesis

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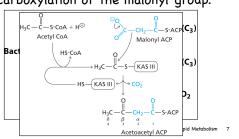




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# Fatty Acid Synthesis

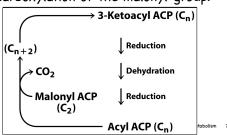
The ligation of an acetyl group to the growing chain is coupled to the decarboxylation of the malonyl group.



7-2

# Fatty Acid Synthesis

The ligation of an acetyl group to the growing chain is coupled to the decarboxylation of the malonyl group.



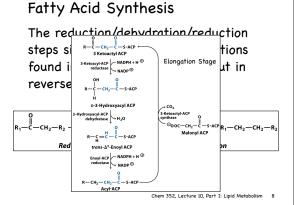
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# Fatty Acid Synthesis

The reduction/dehydration/reduction steps similar to a series of reactions found in the citric acid cycle, but in reverse order.

$$\begin{array}{c} \mathsf{O} \\ \| \mathsf{R}_1 - \mathsf{C} - \mathsf{C} \mathsf{H}_2 - \mathsf{R}_2 & \longrightarrow \mathsf{R}_1 - \mathsf{C} - \mathsf{C} \mathsf{H}_2 - \mathsf{R}_2 & \longrightarrow \mathsf{R}_1 - \mathsf{C} = \mathsf{C} - \mathsf{R}_2 & \longrightarrow \mathsf{R}_1 - \mathsf{C} \mathsf{H}_2 - \mathsf{R}_2 \\ \mathsf{H} \\ \mathsf{Reduction} & \mathsf{Dehydration} & \mathsf{Reduction} \\ \end{array}$$

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## Fatty Acid Synthesis

The reduction/dehydration/reduction steps similar to a series of reactions found in the citric acid cycle, but in reverse order.

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8-3

Fatty Acid Synthesis

The elongation continues until reaching 16 carbons (palmitic acid).

• The palmitoyl group is cleaved from the ACP by a thioesterase.

Palmitoyl-ACP 
$$\xrightarrow{\text{H}_2\text{O}}$$
 Palmitate (C<sub>16</sub>) + HS-ACP

9-1

Fatty Acid Synthesis

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Palmitoyl-ACP 
$$\xrightarrow{\text{H}_2\text{O}}$$
 Palmitate (C<sub>16</sub>) + HS-ACP

Acetyl CoA + 7 Malonyl CoA + 14 NADPH + 14 H $^{\oplus}$   $\longrightarrow$ 

Palmitate+ 7 CO<sub>2</sub> + 14 NADP<sup>⊕</sup> + 8 HS-CoA + 6 H<sub>2</sub>O

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Chem 352, Lecture 10, Part I: Lipid Metabolism

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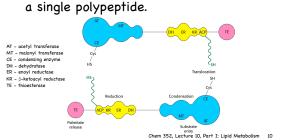
Palmitoyl-ACP 
$$\xrightarrow{\text{H}_2\text{O}}$$
 Palmitate (C<sub>16</sub>) + HS-ACP

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## Fatty Acid Synthesis

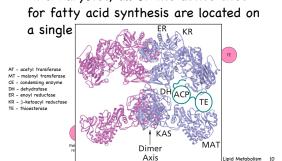
In eukaryotes, all of the active sites for fatty acid synthesis are located on



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Fatty Acid Synthesis

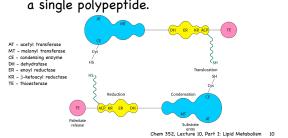
In eukaryotes, all of the active sites



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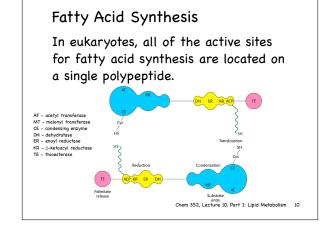
Fatty Acid Synthesis

In eukaryotes, all of the active sites for fatty acid synthesis are located on a single polypeptide.



# Fatty Acid Synthesis In eukaryotes, all of the active sites for fatty spiral of the active sites ated on a single AT - octyl transferase MT - malarny transferase CE - dehydrotase RR - envir feductase RR - shebacoyl reductase RF - thioesterase





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| Fatty Acid Synthesis  |    |
|---|----|
| In eukaryotes, all of the active sites  |    |
| for f @ @ d on  |    |
| a sin   |    |
| AT - acetyl transfer  AT - acetyl transfer  CE - condensing ency  DH - debydratise  ER - encyl reductate  KR - S-kebool redu  TE - thioesterase  CGA Malloy ISI |    |
| Chem 35Z, Lecture 10, Part T: Lipid Metabolism  | 10 |

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|                                    | Fatty Acid Synthesis   |  |  |  |  |
|------------------------------------|--|--|--|--|--|
|                                    | In eukaryotes, all of the active sites for fatty acid synthesis are located on a single polypeptide.   |  |  |  |  |
| MT<br>CE -<br>DH -<br>ER -<br>KR - | - acetyl transferase - malonyl transferase - malonyl transferase - condersing enzyme - dehydratae - s->-ketocyl reductase - sketocyl re |  |  |  |  |

| <b>Fatty</b> | Acid | Syn | thesis |
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After palmitic acid is synthesized it is elongated and desaturated to form other fatty acids

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#### Fatty Acid Synthesis

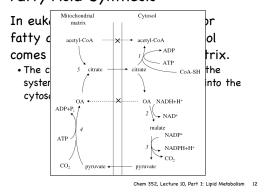
In eukaryotes, the acetyl-CoA for fatty acid synthesis in the cytosol comes from the mitochonrial matrix.

 The citrate/pyruvate shuttle is one of the systems used to move acetyl-CoA out into the cytosol.

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#### Fatty Acid Synthesis



12-2

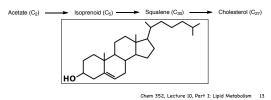
## Fatty Acid Synthesis

In eukaryotes, the acetyl-CoA for fatty acid synthesis in the cytosol comes from the mitochonrial matrix.

 The citrate/pyruvate shuttle is one of the systems used to move acetyl-CoA out into the cytosol. 12-3

Cholesterols is used to modulate the physical properties of membranes in animals

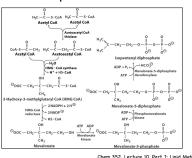
• It is also the starting point for the synthesis of all other steroid molecules



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# Cholesterol Synthesis

Acetate to Isoprenoid



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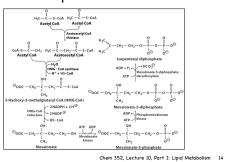
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| Cholesterol Synth   | asis   |
|---|--|
| Cholesterol Syllin  | Acetyl-CoA > 3-hydroxy-3-methylgiutaryl-CoA                    |
| Acetate to Isoprenoic   | Thiolase (HMG-CoA)  HMG-CoA  Synthese HMG-CoA reductase        |
|   | Acetoacetyl-CoA Mevalonic acid                                 |
| H <sub>1</sub> C-C-S-COA H <sub>2</sub> C-C-S-COA                                 | Mevalonate kinase  |
| Acetyl CoA Acetyl CoA   | Mevalonate-5-phosphate  Phosphornevalonate kinase              |
| Acetoacetyl CoA<br>thiolase H   | V  |
| CoA-S-C-CH1 H <sub>2</sub> C-C-CH2-C-S-CoA H                                      | Isopentenyi-PP Mevalonate-5-pyrophosphate                      |
| Acetyl CoA Acetoacetyl CoA  | Dimethylallyl-PP - Isopentenyl-5-pyrophosphate (PP)            |
| H <sub>2</sub> O<br>HMG - CoA synthase  | Famesyl-PP synthase BISPHOSPHONATES                            |
| ↓ H* + HS-CoA<br>OH O   | Geranyl PP   |
| ©00C − CH <sub>2</sub> − C − CH <sub>2</sub> − C − S − CoA                        | Famesyl-PP synthese<br>BISPHOSPHONATES                         |
| CH <sub>3</sub> 3-Hydroxy-3-methylglutaryl CoA (HMG CoA)                          | Geranylgeranyl-PP Geranylgeranyl- / Squalene synthase          |
| HMG-CoA<br>2 NADP⊕  | PP synthase Squalene Synthase Squalene Squalene                |
| HS-COA  | Squatene monoxygenase 2,3 oxidosqualene                        |
| OH ATP ADP  OOC − CH2− C − CH2− CH2− OH → ○                                       | HEME A NADPH Squalene epoxydase                                |
| CH <sub>3</sub> CH <sub>2</sub> Ch <sub>2</sub> Ch <sub>3</sub> Mevalonate kinase | PRENYLATED DOLICHOL Lanosterol PROTEINS UBIQUINON 19 reactions |

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# Cholesterol Synthesis

Acetate to Isoprenoid



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Cholesterol Synthesis

Isoprenoid to Squalene

Chem 352, Lecture 10, Part I: Lipid Metabolism 16

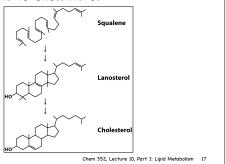
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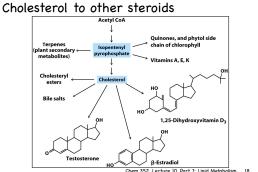
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| H <sub>3</sub> C = CH I Isopentenyl diphosphate  |                       |
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| Fameyi   |                       |
| djohosphate (C <sub>1</sub> 3) Squalere syrillare  (C <sub>1</sub> 3) Squalere syrillare | ;                     |
| 279, — Mag ©   |                       |
| Squalene (C <sub>30</sub> )  | : Lipid Metabolism 16 |

Cholesterol Synthesis

Squalene to Cholesterol



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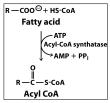


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Fatty acid oxidation

The catabolism of fatty acids takes place in the mitochondria

• The fatty acid must first be activated to an acyl-CoA

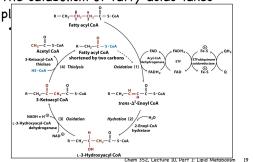


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19-1

Fatty acid oxidation

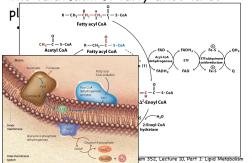
The catabolism of fatty acids takes



19-2

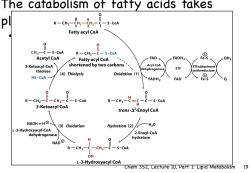
Fatty acid oxidation

The catabolism of fatty acids takes



## Fatty acid oxidation

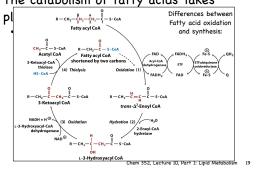
The catabolism of fatty acids takes



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## Fatty acid oxidation

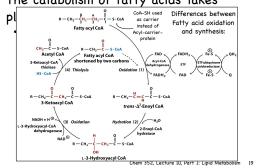
The catabolism of fatty acids takes



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| Fatty | acid | oxidation |
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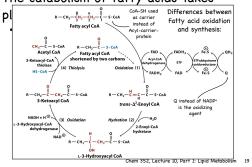
The catabolism of fatty acids takes



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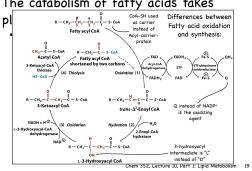
Fatty acid oxidation

The catabolism of fatty acids takes



## Fatty acid oxidation

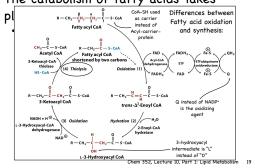
The catabolism of fatty acids takes



19-8

#### Fatty acid oxidation

The catabolism of fatty acids takes

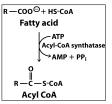


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# Fatty acid oxidation

The catabolism of fatty acids takes place in the mitochondria

• The fatty acid must first be activated to an acyl-CoA

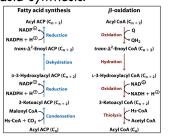


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## Fatty acid oxidation

In many respects it is the reverse of fatty acid synthesis.



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## Fatty acid oxidation

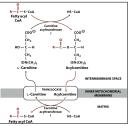
In many respects it is the reverse of

| Fatty acid synthesis   | β-oxidation   |              |              |
|--|---|--------------|--------------|
| Acyl ACP (C <sub>n+2</sub> )  NADP <sup>⊕</sup> Reduction                      | Acyl CoA (C <sub>n+2</sub> )  | Synthesis    | Oxidation    |
| NADPH + H <sup>⊕</sup> ✓ Reduction<br>trans-Δ²-Enoyl ACP (C <sub>n + 2</sub> ) | Oxidation $Q$ $QH_2$ $trans-\Delta^2$ -Enoyl CoA $(C_{n+2})$                        | Cytosol      | Mitochondria |
| Dehydration D-3-Hydroxylacyl ACP (C <sub>n+2</sub> )                           | Hydration<br>L-3-Hydroxylacyl CoA (C <sub>n + 2</sub> )                             | NADPH        | NAD+ and Q   |
| NADP⊕ Reduction NADPH + H⊕ Reduction 3-Ketoacyl ACP (C <sub>n+2</sub> )        | Oxidation NAD <sup>©</sup> NADH + H <sup>©</sup> 3-Ketoacyl CoA (C <sub>n+2</sub> ) | Acyl-ACP     | Acyl-CoA     |
| Malonyl CoA Hs-CoA + CO <sub>2</sub> Condensation                              | Thiolysis Acetyl CoA  | D-3-Hydroxy- | L-3-Hydroxy- |
| Acyl ACP (C <sub>n</sub> )   | Acyl CoA (C <sub>n</sub> )  |              |              |

| fatty acid  | l synthesis.  |                           |                       |
|---|---|---------------------------|-----------------------|
| Fatty acid synthesis  | $\beta$ -oxidation  |                           |                       |
| Acyl ACP $(C_{n+2})$<br>NADP $\bigoplus \checkmark \uparrow$  | Acyl CoA (C <sub>n + 2</sub> ) Oxidation  | Synthesis                 | Oxidation             |
| NADPH + H <sup><math>\oplus</math></sup> $\nearrow$ Reduction<br>trans- $\Delta^2$ -Enoyl ACP (C <sub>n+2</sub> ) | $OXIDATION$ $\rightarrow$ QH <sub>2</sub> $trans-\Delta^2$ -Enoyl CoA (C <sub>n+2</sub> ) | Cytosol                   | Mitochondria          |
| Dehydration D-3-Hydroxylacyl ACP (C <sub>n+2</sub> )  | Hydration  L-3-Hydroxylacyl CoA (C <sub>n+2</sub> )                                       | NADPH                     | NAD+ and Q            |
| NADP⊕ ↑ Reduction   | Oxidation NAD®  | Acyl-ACP                  | Acyl-CoA              |
| 3-Ketoacyl ACP (C <sub>n+2</sub> )  Malonyl CoA Condensation  Hs-CoA + CO <sub>2</sub>                            | 3-Ketoacyl CoA (C <sub>n+2</sub> )  Thiolysis  → Hs-CoA  Acetyl CoA                       | D-3-Hydroxy-              | L-3-Hydroxy-          |
| Acyl ACP (C <sub>n</sub> )  | Acyl CoA (C <sub>n</sub> )  |                           |                       |
|   | Che   | m 352, Lecture 10, Part I | : Lipid Metabolism 21 |
|   |   |                           |                       |

## Fatty acid oxidation

Fatty acids enter the mitochondria by way of the carnitine shuttle.



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#### ATP Generation

ATP generation of the the complete oxidation of stearic acid (18:0)

Stearoyl-CoA + 8 CoA-SH + 8 Q + 8 NAD+  $\rightarrow$  9 Acetyl-CoA + 8 QH2 + 8 NADH + 8 H+

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| 23-1 |  |  |
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#### ATP Generation

ATP generation of the the complete oxidation of stearic acid (18:0)

Stearoyl-CoA + 8 CoA-SH + 8 Q + 8 NAD $^{+}$   $\rightarrow$  9 Acetyl-CoA + 8 QH $_2$  + 8 NADH + 8 H $^{+}$ 

| Source                    | ATP's |
|---------------------------|-------|
| 8 QH <sub>2</sub>         | 12    |
| 8 NADH                    | 20    |
| 9 Acetyl-CoA              | 90    |
| Activation of<br>Stearate | -2    |
| Total                     | 120   |

## 23-3 ATP Generation ATP generation of the the complete oxidation of stearic acid (18:0) Stearoyl-CoA + 8 CoA-SH Enthusid + 8 G 8 QH<sub>2</sub> + 8 NADH + 8 H\* Fatty acid ATP Acyl-CoA synthatase →AMP + PP<sub>i</sub> Acyl CoA Activation of Stearate 120 Total Chem 352, Lecture 10, Part I: Lipid Metabolism 23 23-4 ATP Generation ATP generation of the the complete oxidation of stearic acid (18:0) Stearoyl-CoA + 8 CoA-SH + 8 Q + 8 NAD $^+$ $\rightarrow$ 9 Acetyl-CoA + 8 QH $_2$ + 8 NADH + 8 H $^+$ ATP's Source 8 QH<sub>2</sub> 12 8 NADH 20 9 Acetyl-CoA 90 Activation of Stearate -2 Total 120 Chem 352, Lecture 10, Part I: Lipid Metabolism 23 24-1 ATP Generation ATP generation of the the complete oxidation of steric acid (18:0) • Compared to Glucose (on a per C basis) Chem 352, Lecture 10, Part I: Lipid Metabolism 24 24-2 ATP Generation ATP generation of the the complete oxidation of steric acid (18:0) • Compared to Glucose (on a per C basis) ATP's Source 3 x 32 = 96 3 x Glucose Stearate 120

| ATP Generation  | 25-1 |
|---|------|
| ATP generation of the the complete oxidation of stearic acid (18:0) • Compared to Fatty Acid Synthesis  |      |
| Chem 352, Lecture 10, Part T: Lipid Metabolism 25   |      |
| ATP Generation  ATP generation of the the complete oxidation of stearic acid (18:0)  • Compared to Fatty Acid Synthesis  Source ATP's  8 Acetyl-CoA 8 8 Malonyl-CoA 8 8 Rounds 16 NADPH 40 9 Acetyl-CoA 9 x 17 = 153 Total 201  | 25-2 |
|   |      |
| ATP Generation  ATP generation of the the complete oxidation of stearic acid (18:0)  • Compared to Fatty Acid Synthesis  Source ATP's  8 Acetyl-CoA → 8 8 Rounds 16 NADPH 40  9 Acetyl-CoA (Calvin cycle) 9 x 17 = 153  Total 201  Yield = 120/201 = 60%  Chem 352, Lecture 10, Part 1: Lipid Metabolism 25 | 25-3 |
| ATP Generation  Regulation of Lipid Metabolism  • Involves same hormones as carbohydrate metabolism  • Glucogon (fasting state)  • Epinephrin (excited state)  • Insulin (fed state)  | 26-1 |

#### 26-2 ATP Generation Regulation of Lipid Metabolism Involvies as carbohydrate met@pinisphrine Glucogon (fasting state) Activate ipases in surpose state) formation and storage · Insulins(fed state) of triacylglycerides Inactivates acetyl-CoA carboxylase Activate acetyl-CoA carboxylase Acetyl-CoA inhibits pyruvate dehydrogenase Malonyl-CoA inhibits Carnitine acyltransferase I Chem 352, Lecture 10, Part I: Lipid Metabolism 26 26-3 ATP Generation Regulation of Lipid Metabolism Involate ydrate met@pi · Gluco 'AERING nd storage Insul nhibits sferase Chem 352, Lecture 10, Part I: Lipid Metabolism 26 26-4 ATP Generation Regulation of Lipid Metabolism InvoGlesasgame&hormones as carbohydrate met@piotisphrine · Glucogon (fasting state) Activate ipases in adipose activate formation and storage • Insulins(fed state) of triacylglycerides Inactivates acetyl-CoA carboxylase Activate acetyl-CoA carboxylase Acetyl-CoA inhibits pyruvate dehydrogenase Malonyl-CoA inhibits Carnitine acyltransferase I

# Transport of lipds in Blood

Lipids are transported by lipoprotein complexes

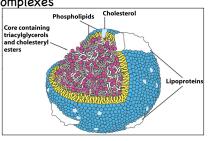
- Chylomicrons
- VLDH (Very Low Density Lipoproteins)
- IDH (Intermediate Density Lipoproteins)
- LDL (Low Density Lipoproteins)
- · HDL (High Density Lipoproteins)

| 27  | 4 |
|-----|---|
| //- |   |

Chem 352, Lecture 10, Part I: Lipid Metabolism 27

## Transport of lipds in Blood

Lipids are transported by lipoprotein complexes



Chem 352, Lecture 10, Part I: Lipid Metabolism 27

#### Transport of lipds in Blood

Lipids are transported by lipoprotein complexes

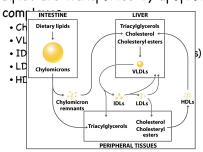
- Chylomicrons
- VLDH (Very Low Density Lipoproteins)
- IDH (Intermediate Density Lipoproteins)
- LDL (Low Density Lipoproteins)
- · HDL (High Density Lipoproteins)

Chem 352, Lecture 10, Part I: Lipid Metabolism 27

#### 27-3

# Transport of lipds in Blood

Lipids are transported by lipoprotein



Chem 352, Lecture 10, Part I: Lipid Metabolism 27

#### 27-4

27-5

## Transport of lipds in Blood

Lipids are transported by lipoprotein complexes

- Chylomicrons
- VLDH (Very Low Density Lipoproteins)
- IDH (Intermediate Density Lipoproteins)
- LDL (Low Density Lipoproteins)
- · HDL (High Density Lipoproteins)

#### Ketone Bodies

Ketone bodies are formed from acetyl-CoA as a soluble circulating source of fat-derived energy.

• Produce under conditions of long-term fasting

Chem 352, Lecture 10, Part I: Lipid Metabolism 28

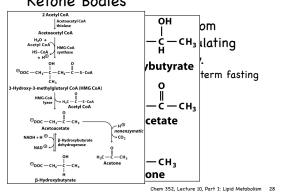
28-1

#### Ketone Bodies

Ketone b acetyl-Cc Source of Produce 
$$\begin{array}{c} OH \\ \ominus OOC-CH_2-CH_2-CH_3 \\ \bullet Produce \end{array}$$
 
$$\begin{array}{c} OH \\ OM \\ Ilating \\ \bullet Produce \end{array}$$
 
$$\begin{array}{c} OH \\ OM \\ \bullet Produce \\ \bullet Produce \end{array}$$
 
$$\begin{array}{c} OH \\ \bullet Produce \\ \bullet P$$

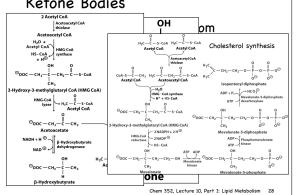
28-2

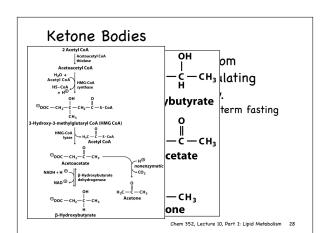
# Ketone Bodies



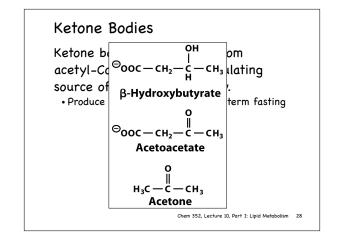
28-3

# Ketone Bodies

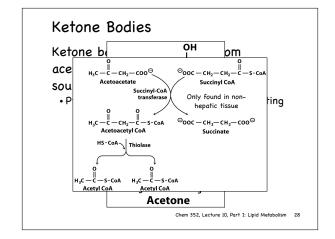




28-5



28-6



28-7

| Ketone 1               | Bodies   |                                     |
|------------------------|--|-------------------------------------|
| source of<br>• Produce | п<br>β-Hvdroxvbutvrate                                       | om<br>Ilating<br>7.<br>term fasting |
|                        | O<br>  <br>H <sub>3</sub> C — C — CH <sub>3</sub><br>Acetone | 0, Part I: Lipid Metabolism 28      |

| Lipid Metabolism   | 29-1 |  |
|--|------|--|
|  |      |  |
|  |      |  |
|  |      |  |
| Chem 352, Lecture 10, Part I: Lipid Metabolism 29  |      |  |
| Lipid Metabolism   | 29-2 |  |
| Question:  Draw a general pathway for converting carbohydrates to fatty acids in a liver cell, and indicate which processes occur in the |      |  |
| cytosol and which occur in mitochondria.   |      |  |
|  |      |  |
|  |      |  |
| Chem 352, Lecture 10, Part I: Lipid Metabolism 29  |      |  |
|  |      |  |
| Lipid Metabolism   | 29-3 |  |
| Lipid Metabolism  Chem 352, Lecture 10, Part 1: Lipid Metabolism 29  | 29-3 |  |
|  | -    |  |
|  | 29-3 |  |
| Chem 352, Lecture 10, Part I: Lipid Metabolism 29  Next Up  Lecture 10 - Part II, Amino acid   | -    |  |
| Chem 352, Lecture 10, Part I: Lipid Metabolism 29  Next Up  Lecture 10 - Part II, Amino acid   | -    |  |
| Chem 352, Lecture 10, Part I: Lipid Metabolism 29  Next Up  Lecture 10 - Part II, Amino acid   | -    |  |