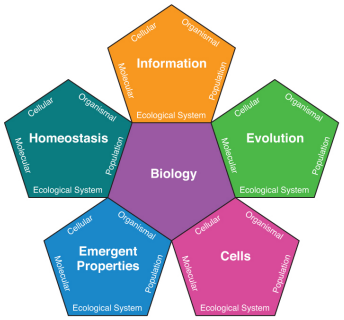
Integrating Concepts in Biology



PowerPoint Slides for Chapter 2:

Central Dogma

2.3 How do cells make proteins?

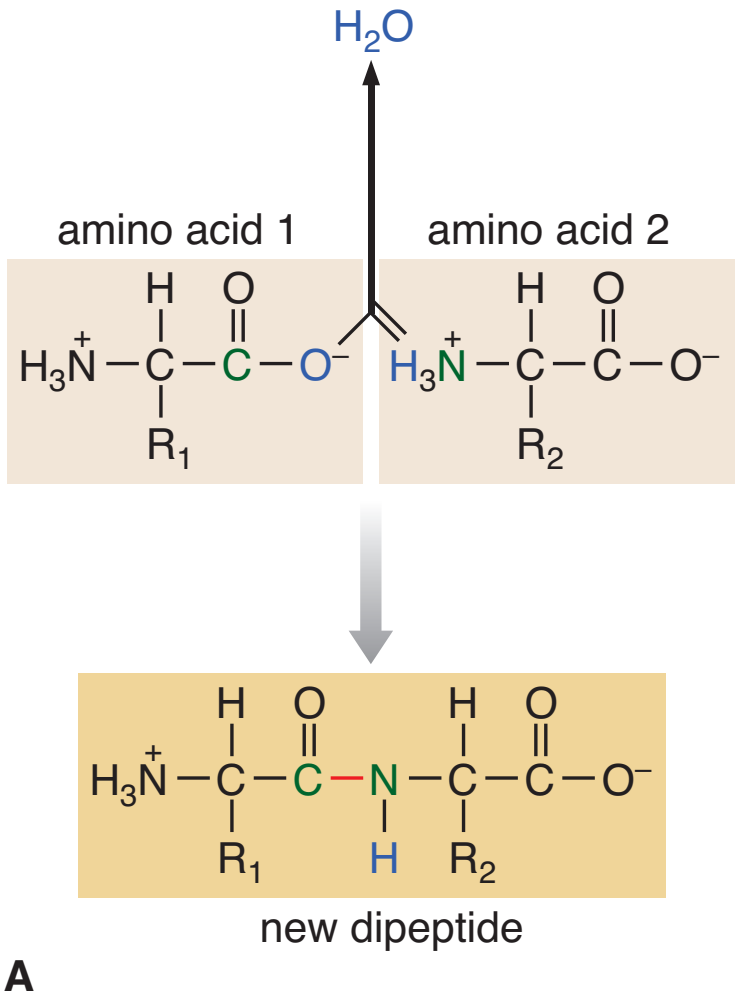
by A. Malcolm Campbell, Laurie J. Heyer, & Christopher Paradise

Title Page

Biology Learning Objectives

- Demonstrate in writing and diagrams how proteins are made.
- Apply the genetic code to deduce the protein encoded by a mRNA.

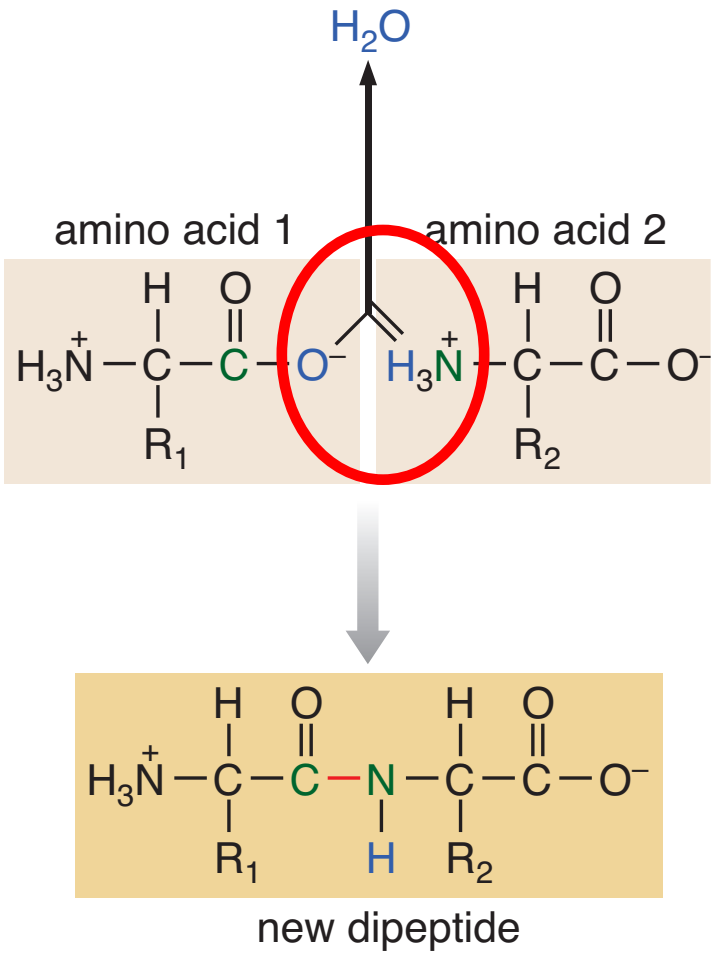
How are Proteins Made?



What is required to build a protein?

Fig. 2.20

Proteins from Amino Acids



A

How do cells make a new (peptide) covalent bond between two amino acids?

Fig. 2.20

Proteins from Amino Acids

ingredients: DNA	chromosomes
energy	energy (ATP and GTP)
tRNA	tRNA
ribosomes	ribosomes (65% rRNA, 35% protein)
mRNA	mRNAs
amino acids	amino acids

Fig. 2.20

Proteins from Amino Acids

chromosomes

energy (ATP and GTP)

tRNA

ribosomes
(65% rRNA, 35% protein)

mRNAs

amino acids

method: gel electrophoresis (denaturing)
stain all proteins dark

Fig. 2.20

Proteins from Amino Acids

all ingredients….

chromosomes

energy (ATP and GTP)

tRNA

ribosomes
(65% rRNA, 35% protein)

mRNAs

amino acids

…proteins produced

Fig. 2.20

Proteins from Amino Acids

omit DNA…

chromosomes

energy (ATP and GTP)

tRNA

ribosomes
(65% rRNA, 35% protein)

mRNAs

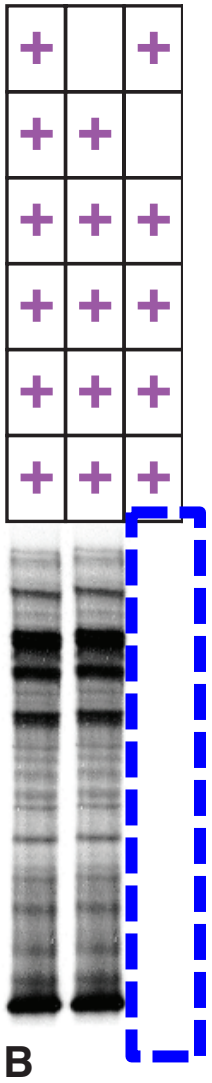
amino acids

…proteins produced

Fig. 2.20

Proteins from Amino Acids

omit energy source…



chromosomes

energy (ATP and GTP)

tRNA

ribosomes
(65% rRNA, 35% protein)

mRNAs

amino acids

…no proteins produced

Fig. 2.20

Proteins from Amino Acids

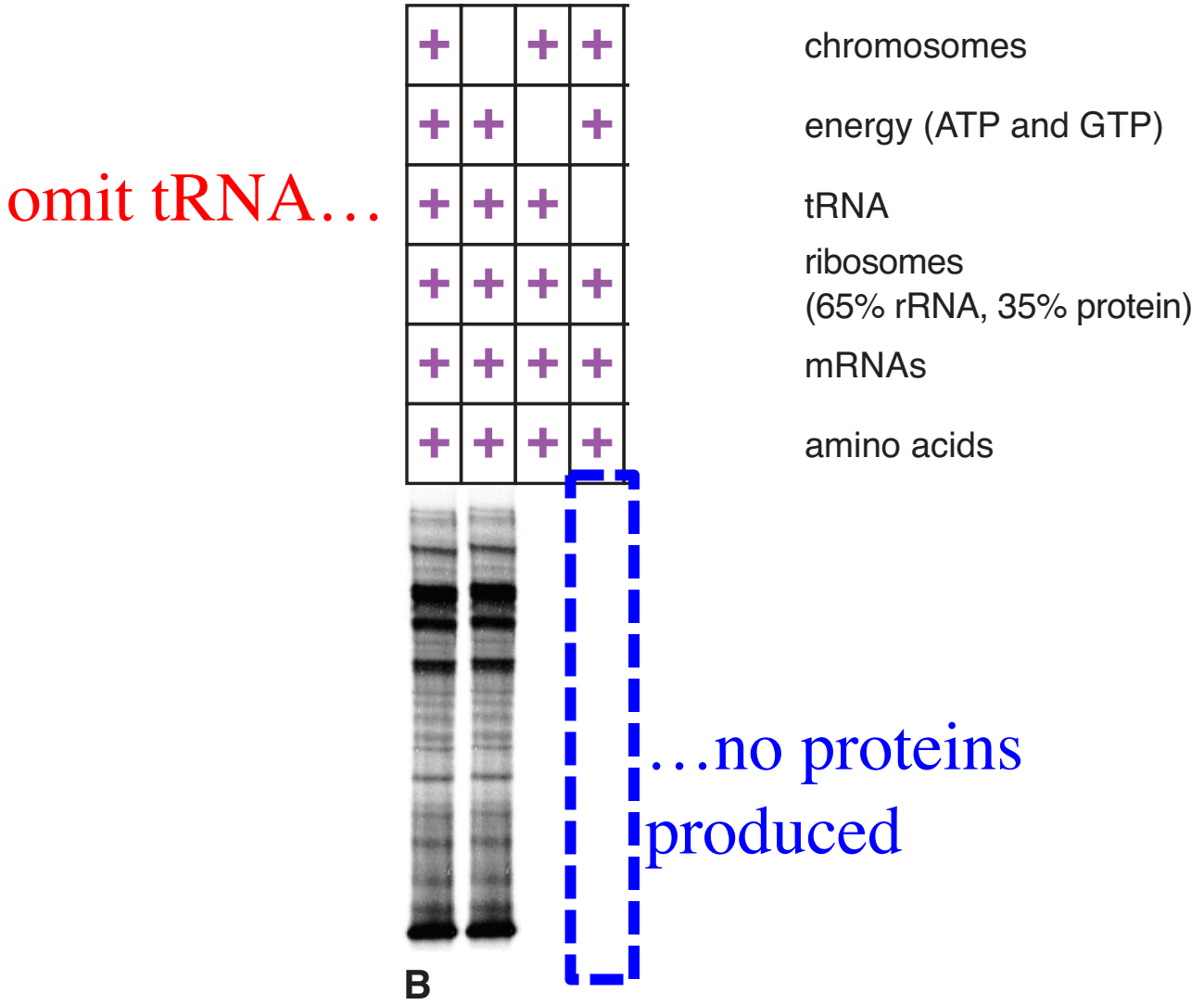
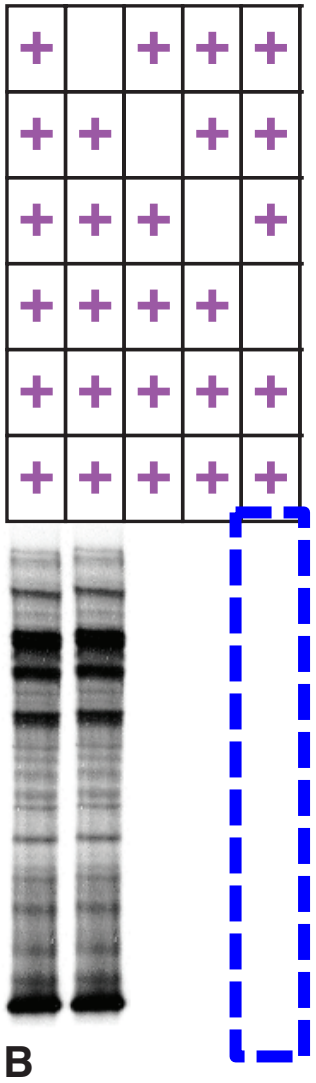


Fig. 2.20

Proteins from Amino Acids

omit ribosomes…



…no proteins produced

Fig. 2.20

Proteins from Amino Acids

omit mRNAs…

…no proteins produced

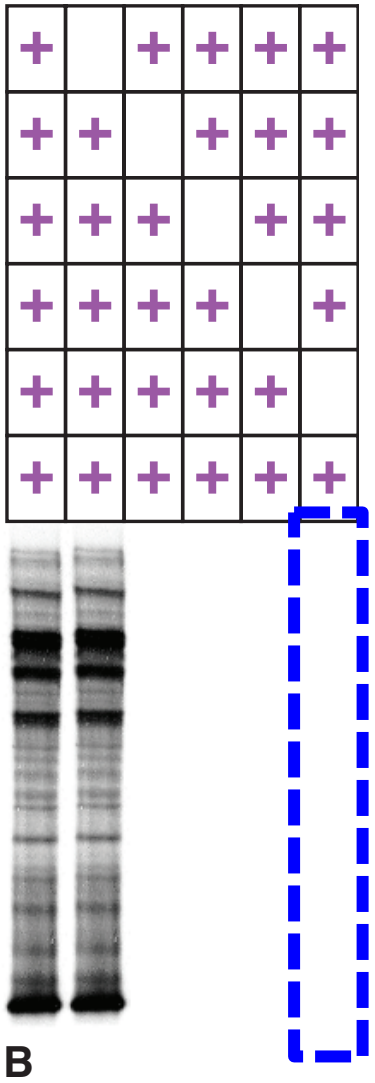


Fig. 2.20

Proteins from Amino Acids

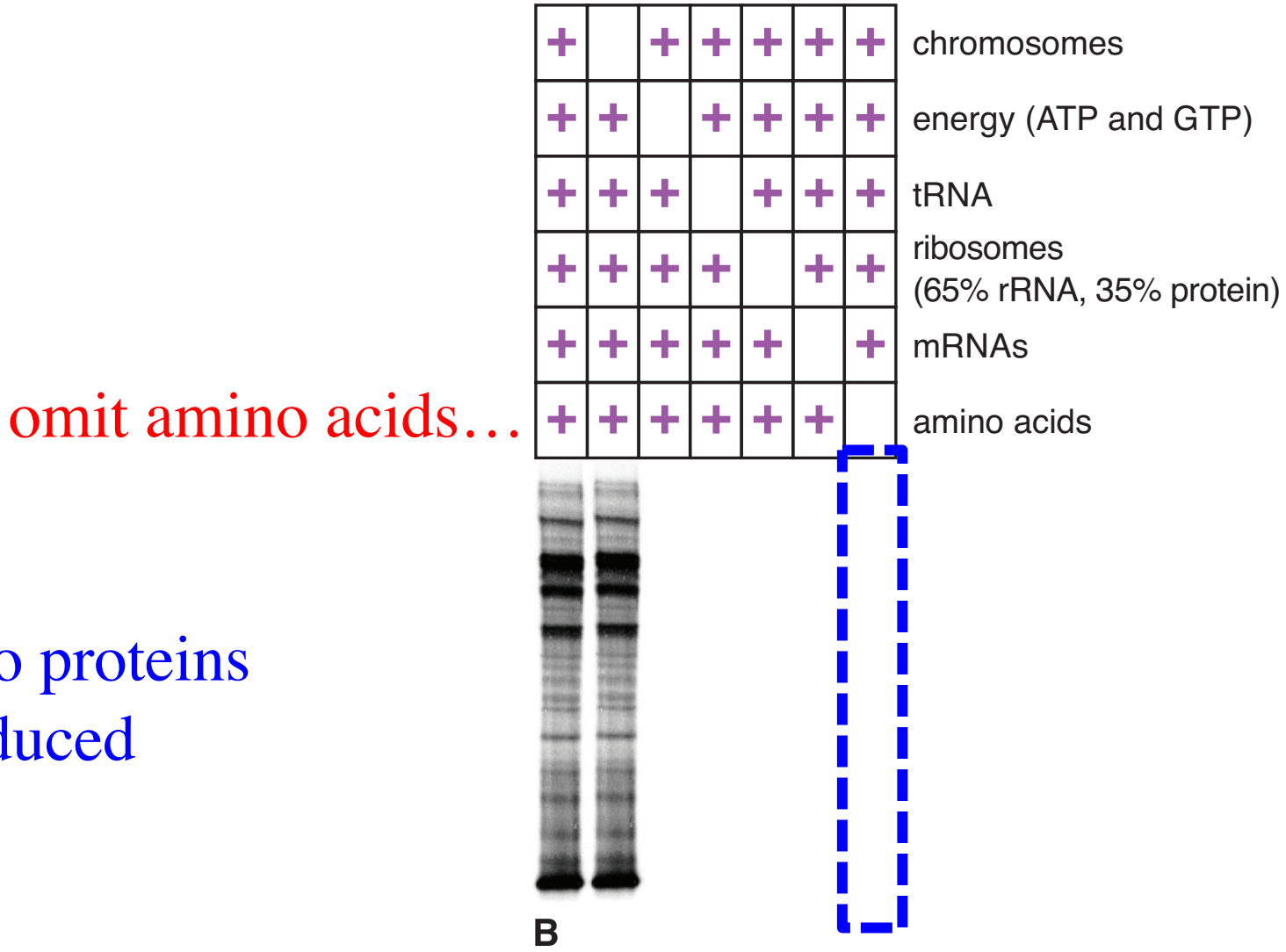
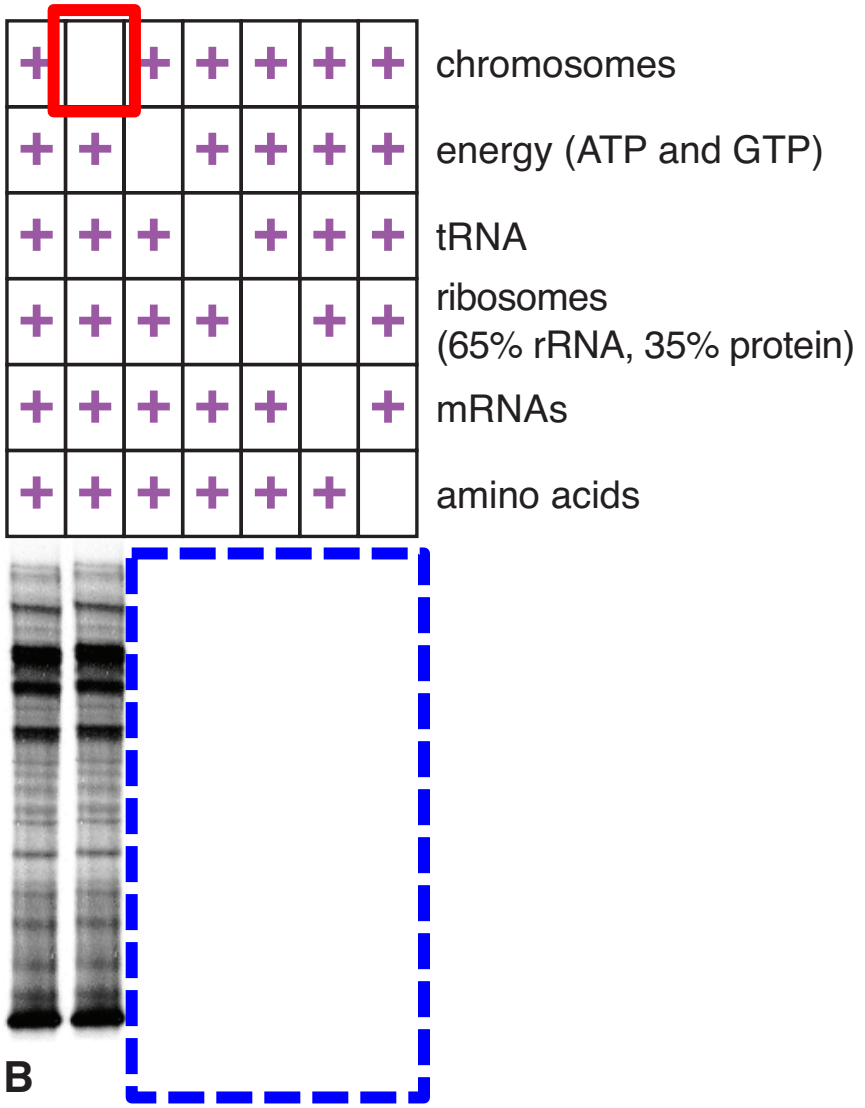


Fig. 2.20

Proteins from Amino Acids

DNA is the only ingredient not used in translation.



…no proteins produced

Fig. 2.20

Watch Translation Movie

www.hhmi.org/biointeractive/translation-advanced-detail

OR

sites.fas.harvard.edu/~biotext/animations/TRANSLATE20b.swf

Fig. 2.20 link

Decoding the First Codon

modern genetic code table
with all possible codons

no one knew about codons
or which amino acids were
coded by particular sequences

	U	C	A	G
U	UUU UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

B

Fig. 2.21

Decoding the First Codon

The very first experiment tested UUUUUUU to see which amino acid was encoded…..

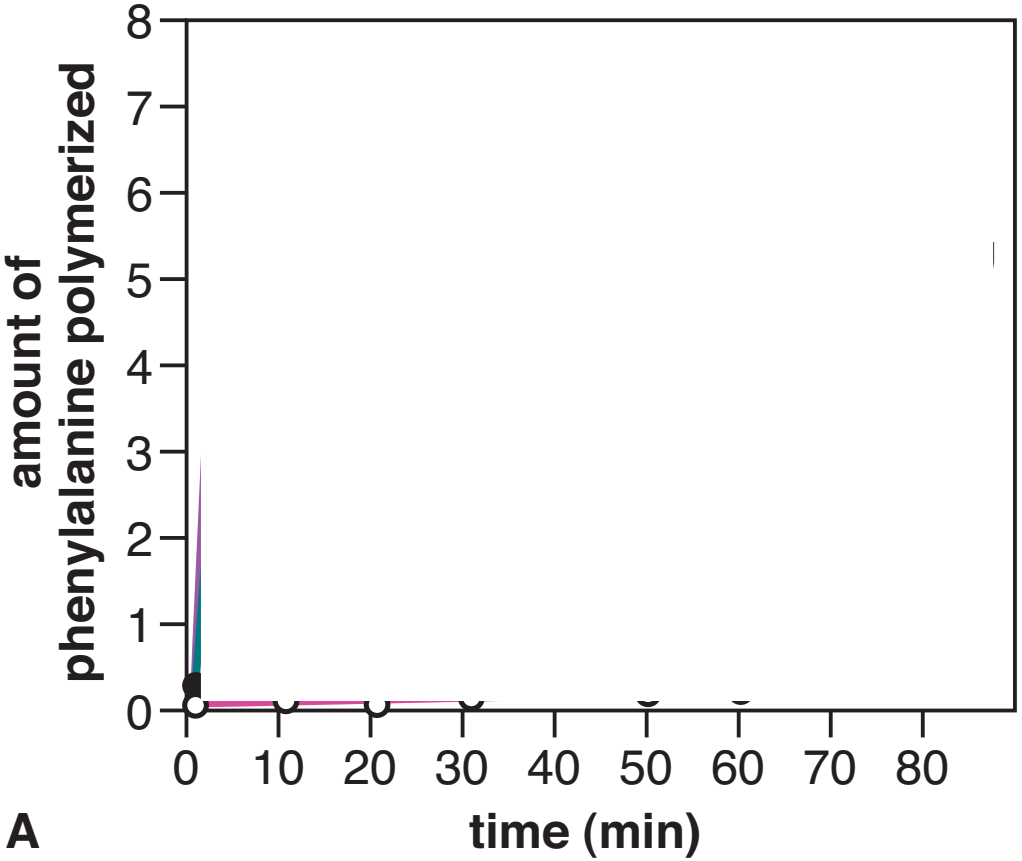
	U	C	A	G
U	UUU UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

B

Fig. 2.21

Decoding the First Codon

measure polymerization over time



A

	U	C	A	G
U	UUU UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

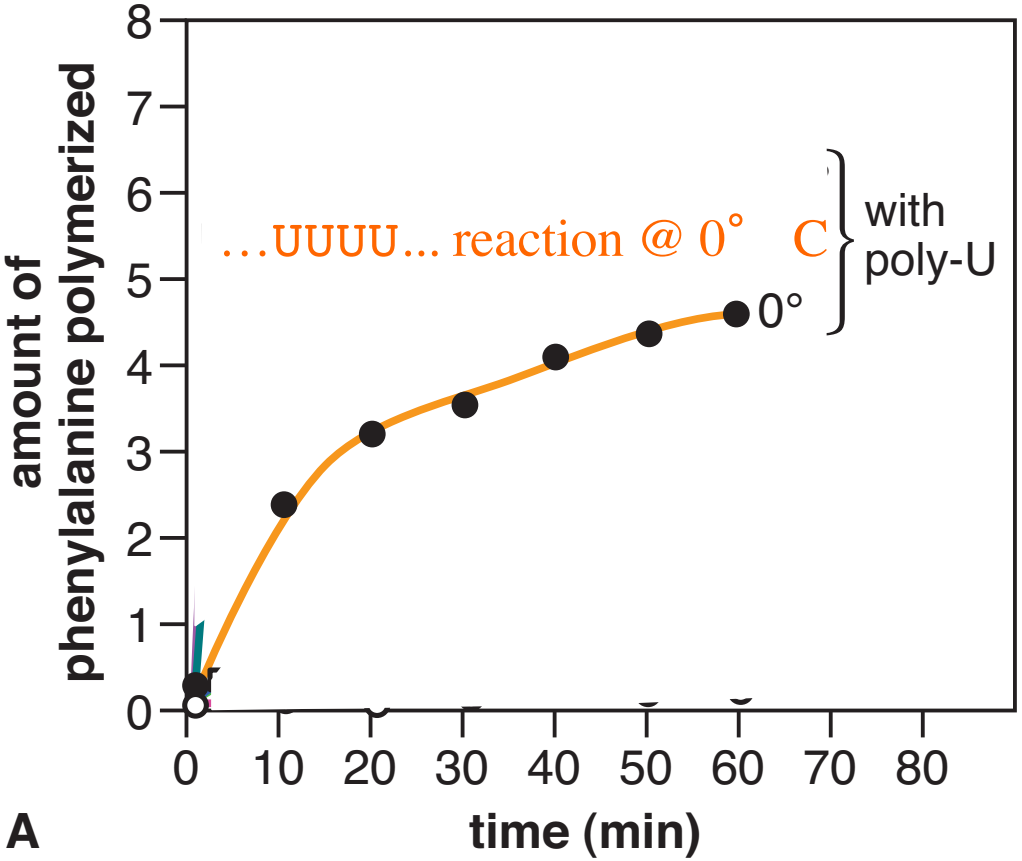
B

Fig. 2.21

modified from Nirenberg and Leder. 1964

Decoding the First Codon

measure polymerization over time



A

	U	C	A	G
U	UUU UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

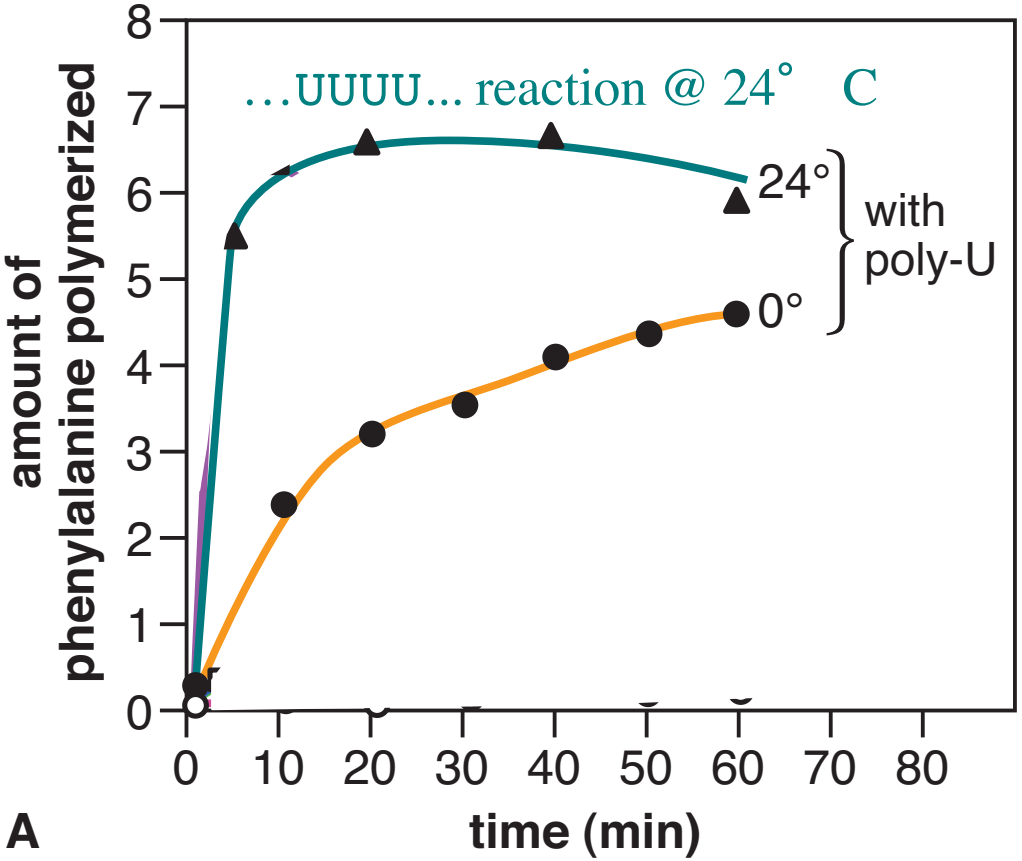
B

Fig. 2.21

modified from Nirenberg and Leder. 1964

Decoding the First Codon

measure polymerization over time



A

	U	C	A	G
U	UUU UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

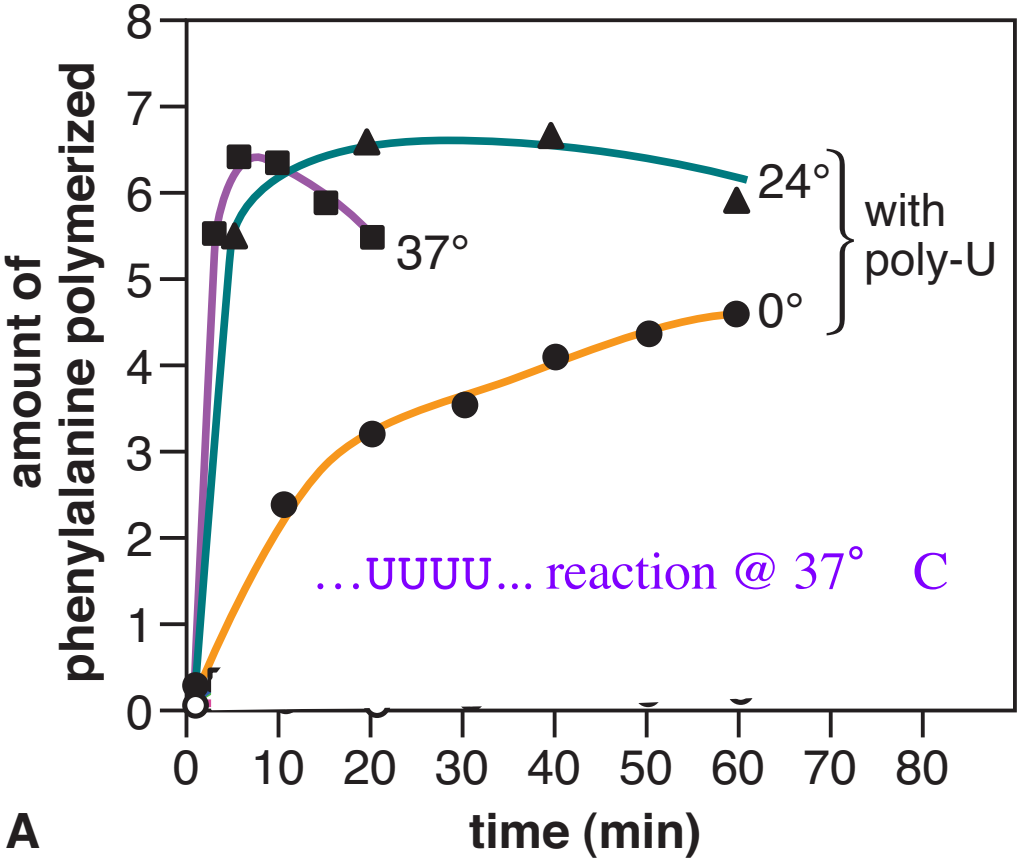
B

Fig. 2.21

modified from Nirenberg and Leder. 1964

Decoding the First Codon

measure polymerization over time



	U	C	A	G
U	UUU phe F UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

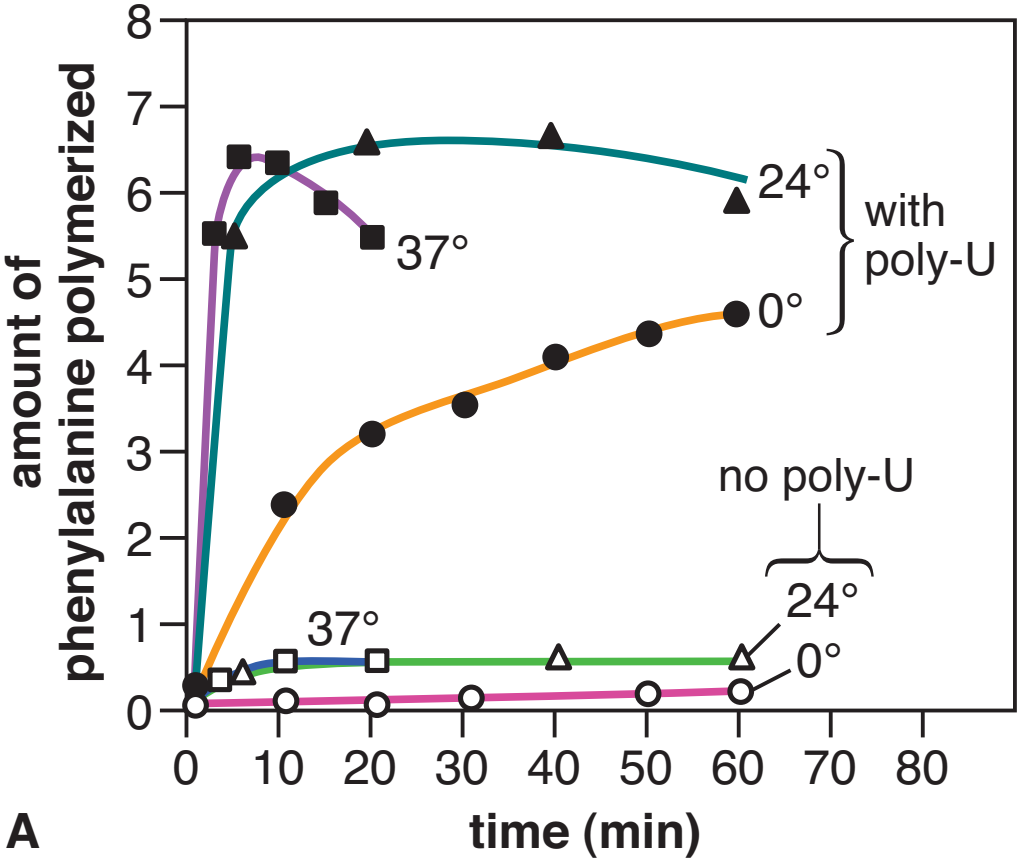
B

Fig. 2.21

modified from Nirenberg and Leder. 1964

Decoding the First Codon

measure polymerization over time



A

	U	C	A	G
U	UUU phe F UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

B

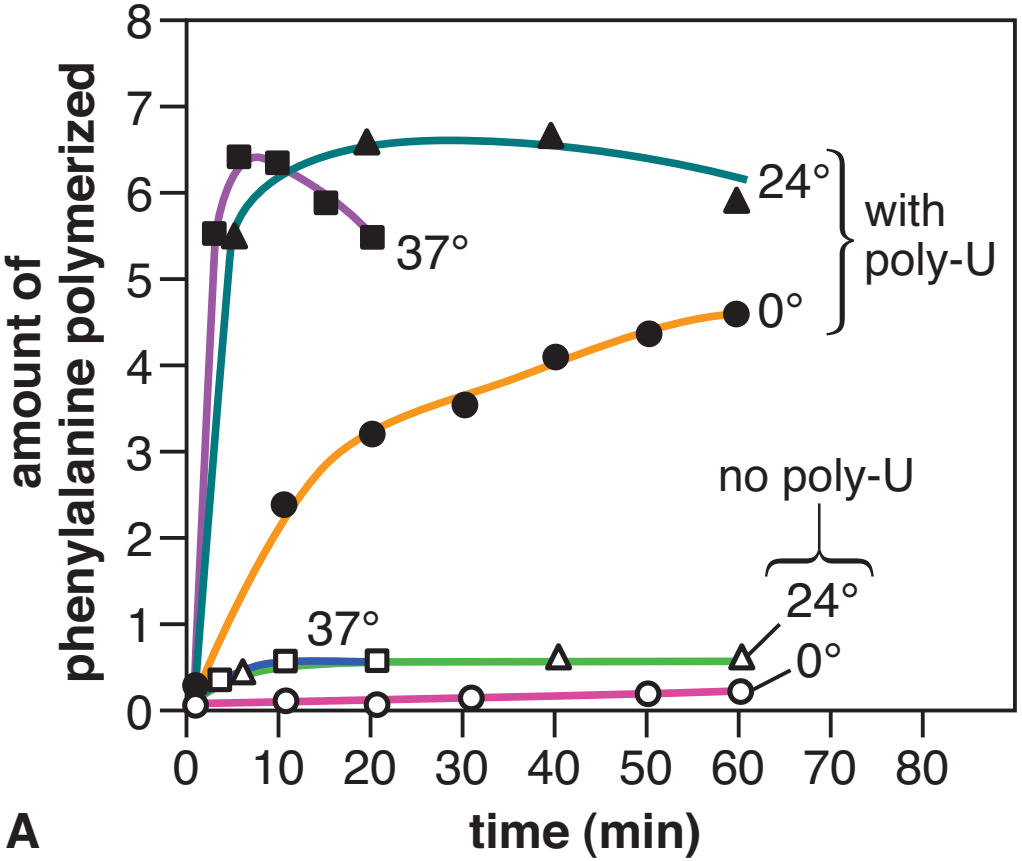
negative control reactions
no polyU mRNA

Fig. 2.21

modified from Nirenberg and Leder. 1964

Decoding the First Codon

UUU encodes phenylalanine (phe = F)



A

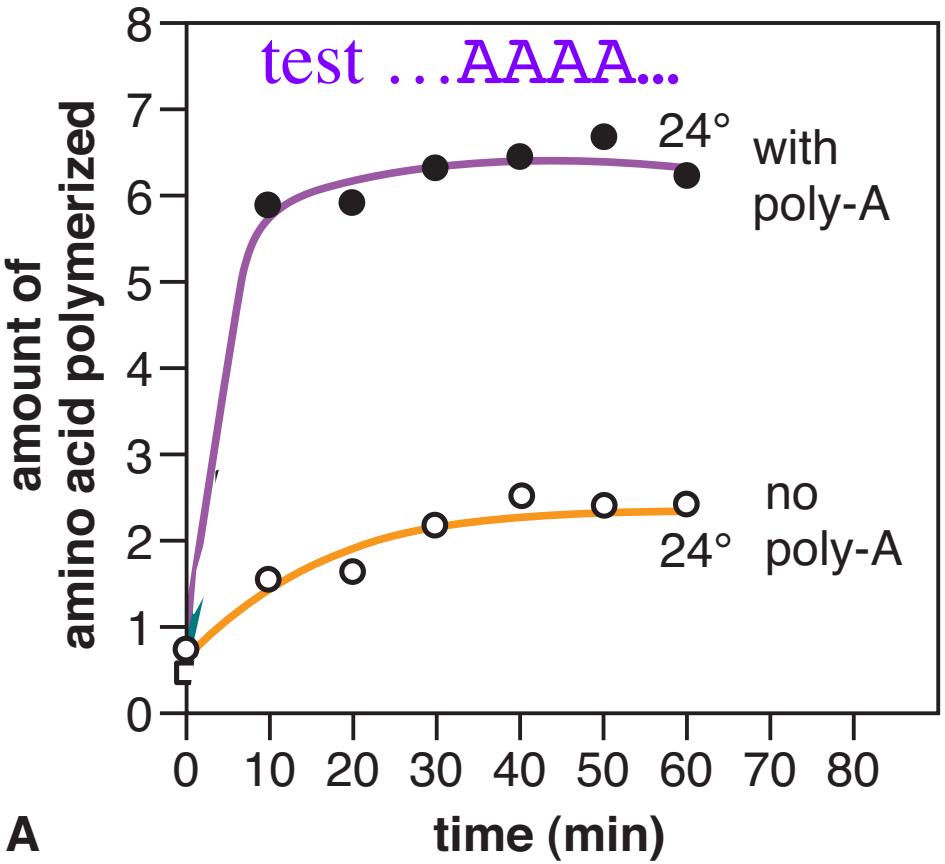
	U	C	A	G
U	UUU phe F UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

B

Fig. 2.21

modified from Nirenberg and Leder. 1964

Decoding the Two More Codons



A

second base in codon

first base in codon	U	C	A	G
U	UUU phe F UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA lys K AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

B

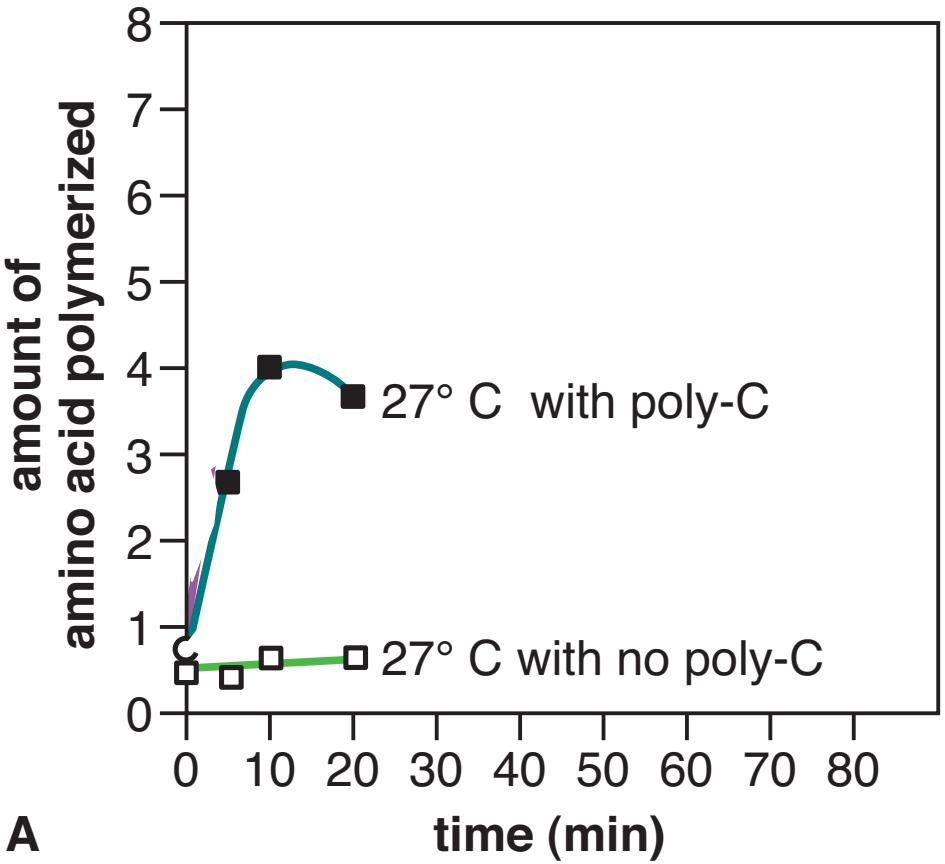
lysine polymers
(lys = K)

Fig. 2.22

modified from Nirenberg and Leder. 1964

Decoding the Two More Codons

test …CCCC…



second base in codon

first base in codon	U	C	A	G
U	UUU phe F UUC UUA UUG	UCU UCC UCA UCG	UAU UAC UAA UAG	UGU UGC UGA UGG
C	CUU CUC CUA CUG	CCU CCC pro P CCA CCG	CAU CAC CAA CAG	CGU CGC CGA CGG
A	AUU AUC AUA AUG	ACU ACC ACA ACG	AAU AAC AAA lys K AAG	AGU AGC AGA AGG
G	GUU GUC GUA GUG	GCU GCC GCA GCG	GAU GAC GAA GAG	GGU GGC GGA GGG

B

lysine polymers
(lys = K)

Fig. 2.22

modified from Nirenberg and Leder. 1964

The Genetic Code

first 3 codons deciphered

first base in codon	U	C	A	G
U	UUU phe F	UCU ser S	UAU tyr Y	UGU cys C
	UUC phe F	UCC ser S	UAC tyr Y	UGC cys C
	UUA leu L	UCA ser S	UAA stop	UGA stop
	UUG leu L	UCG ser S	UAG stop	UGG trp W
C	CUU leu L	CCU pro P	CAU his H	CGU arg R
	CUC leu L	CCC pro P	CAC his H	CGC arg R
	CUA leu L	CCA pro P	CAA gln Q	CGA arg R
	CUG leu L	CCG pro P	CAG gln Q	CGG arg R
A	AUU ile I	ACU thr T	AAU asn N	AGU ser S
	AUC ile I	ACC thr T	AAC asn N	AGC ser S
	AUA ile I	ACA thr T	AAA lys K	AGA arg R
	AUG met M	ACG thr T	AAG lys K	AGG arg R
G	GUU val V	GCU ala A	GAU asp D	GGU gly G
	GUC val V	GCC ala A	GAC asp D	GGC gly G
	GUA val V	GCA ala A	GAA glu E	GGA gly G
	GUG val V	GCG ala A	GAG glu E	GGG gly G

Fig. 2.23

Stop and Start Codons

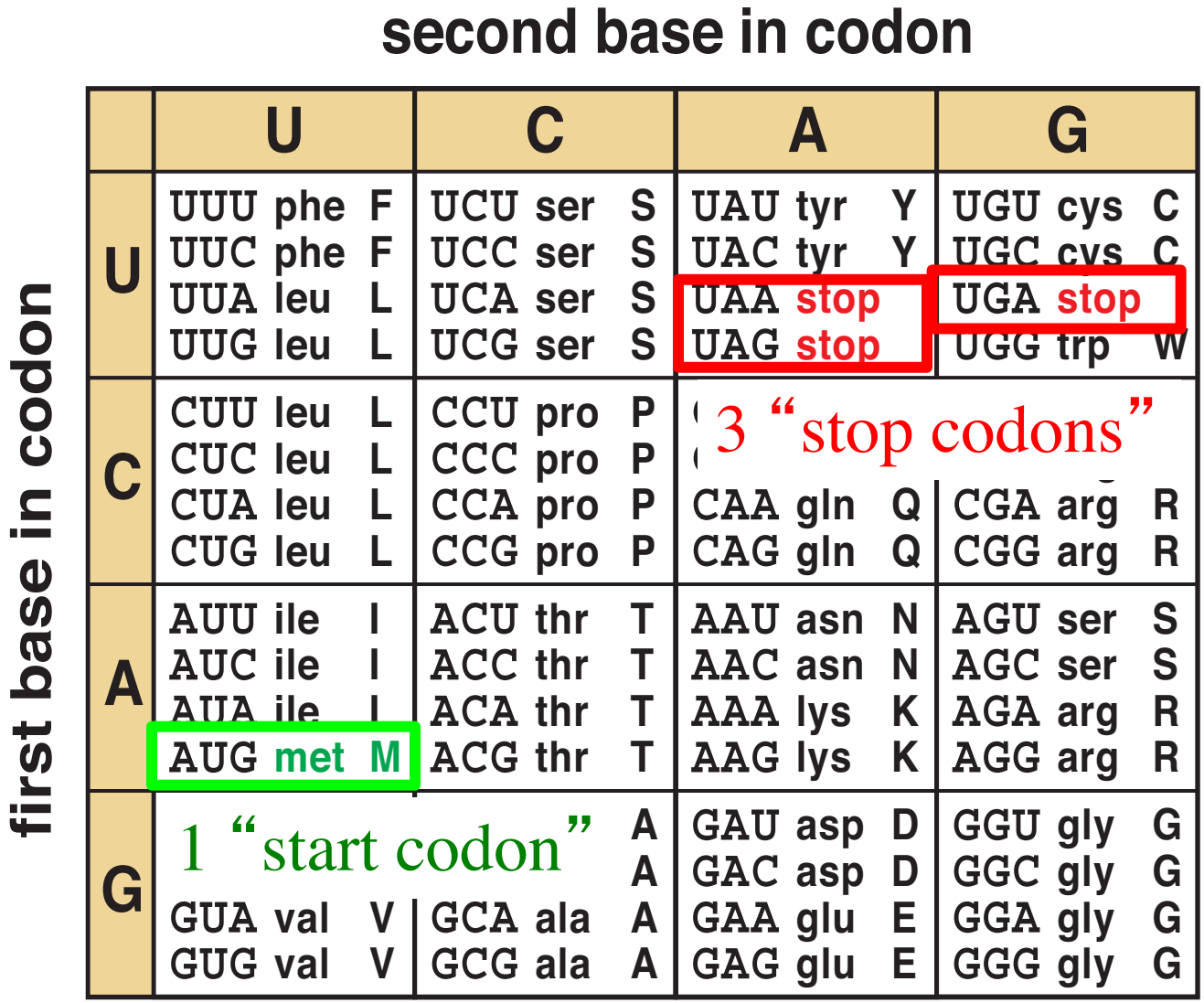


Fig. 2.23

Amino Acids with Six Codons

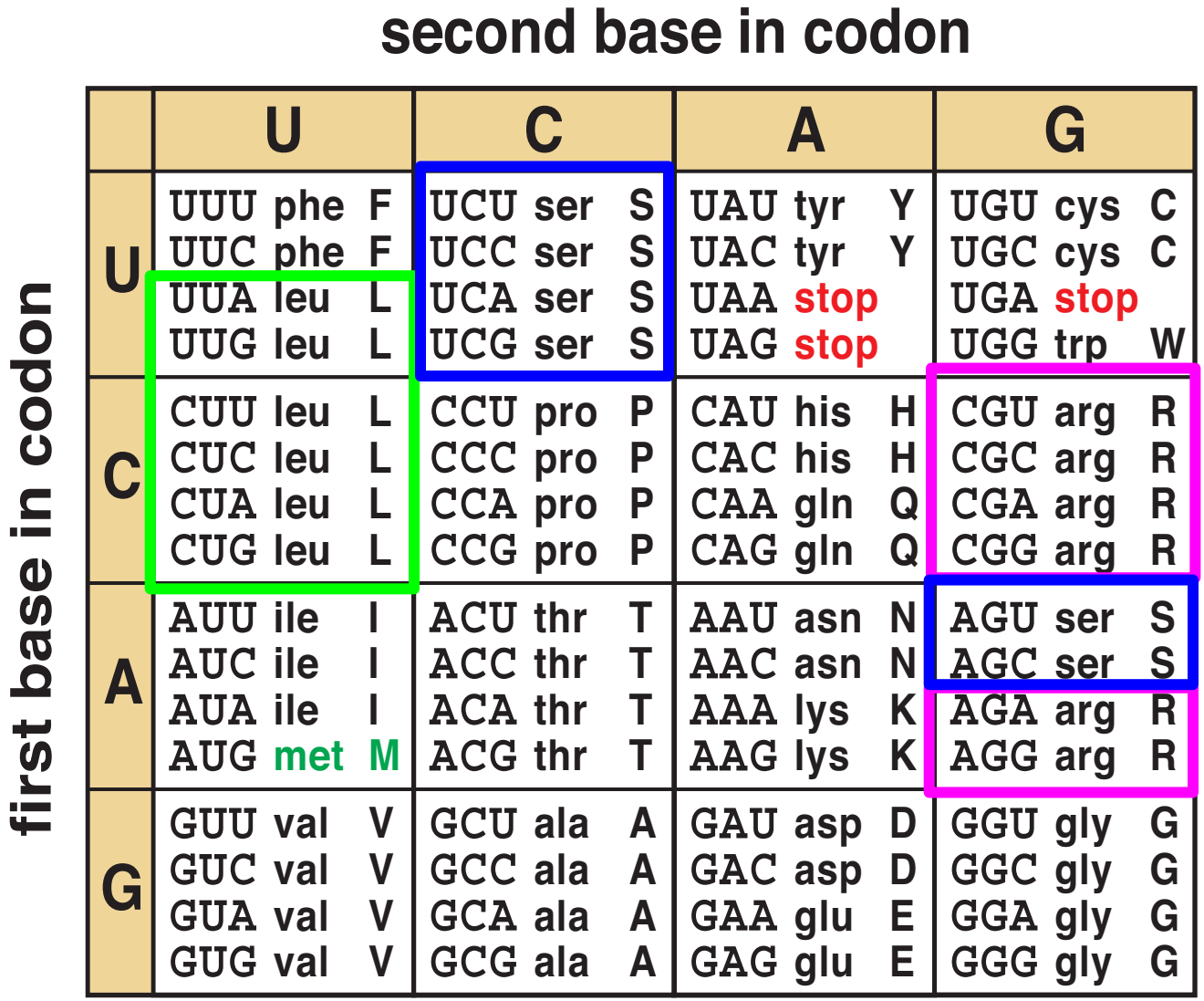


Fig. 2.23

Amino Acids with One Codon

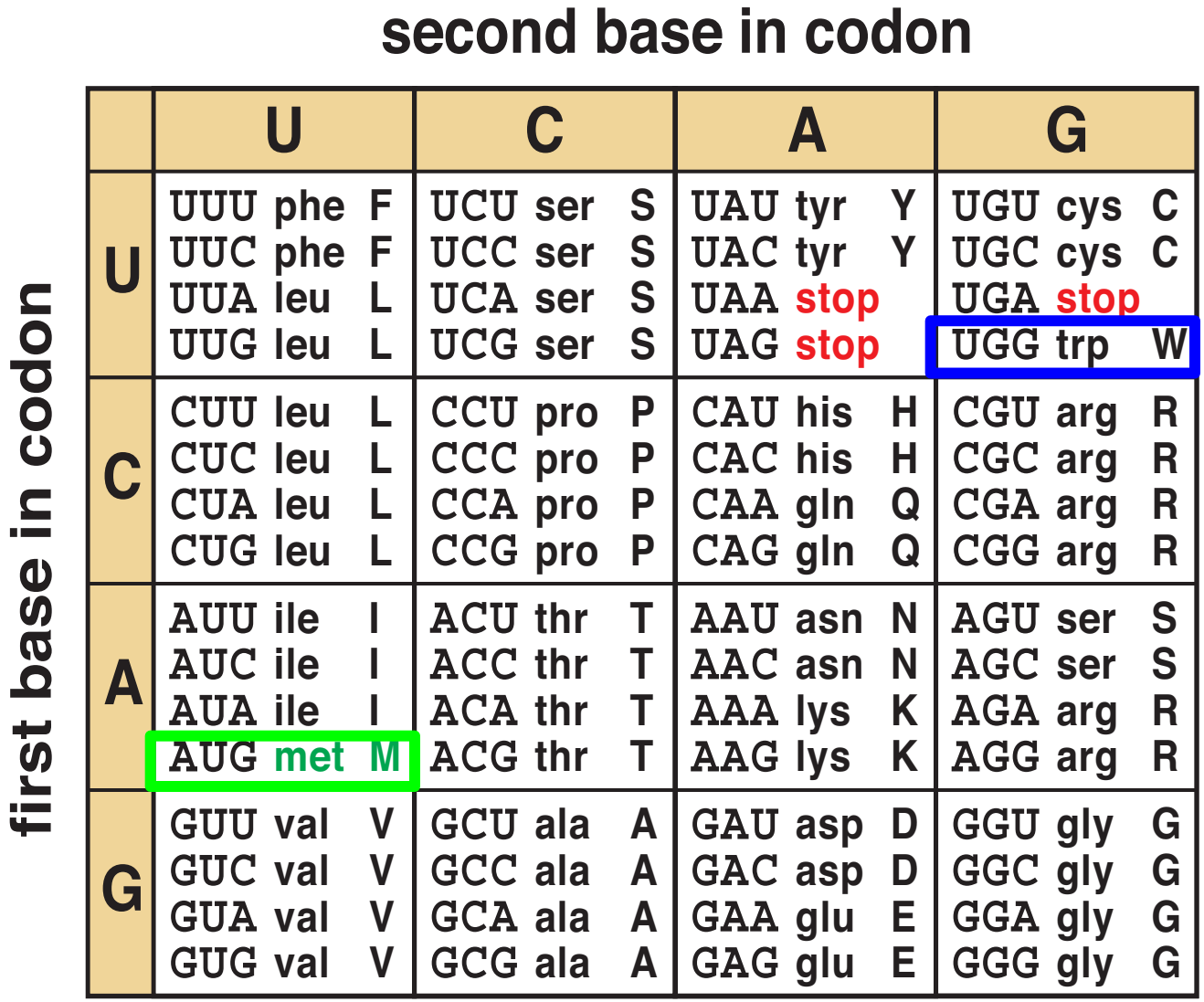


Fig. 2.23