Encryption (Stream)

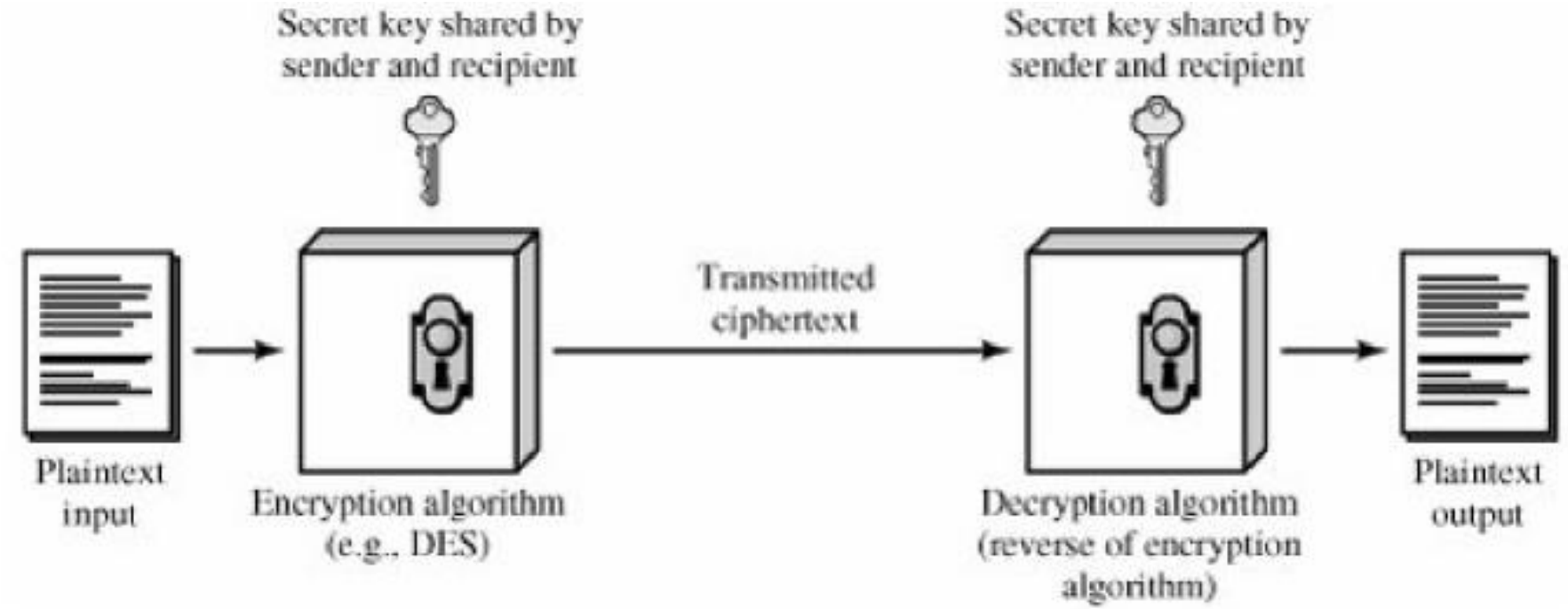
Symmetric Encryption

- Single key for both encryption and decryption
- Was the only type of encryption in use prior to the development of public-key encryption
- Remains by far the most widely used of the two types of encryption

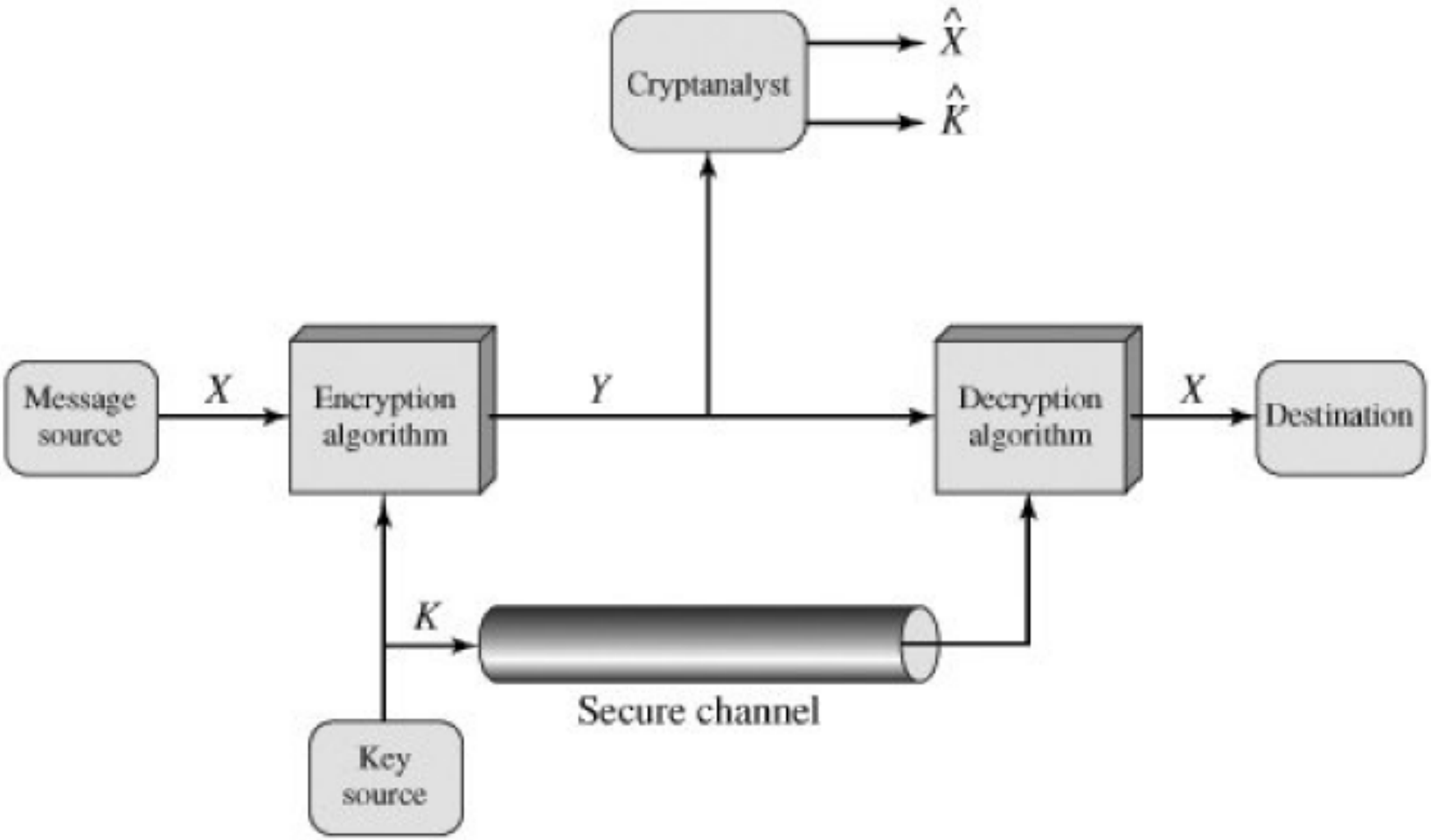
Basic Terminology

- Plaintext: Original message
- Ciphertext: Encrypted message
- Enciphering or encryption: Process of converting from plaintext to ciphertext
- Deciphering or decryption: Restoring the plaintext from the ciphertext
- Cryptographic system or cipher: Schemes used for encryption
- Cryptanalysis: Techniques used for deciphering a message without any knowledge of the enciphering details

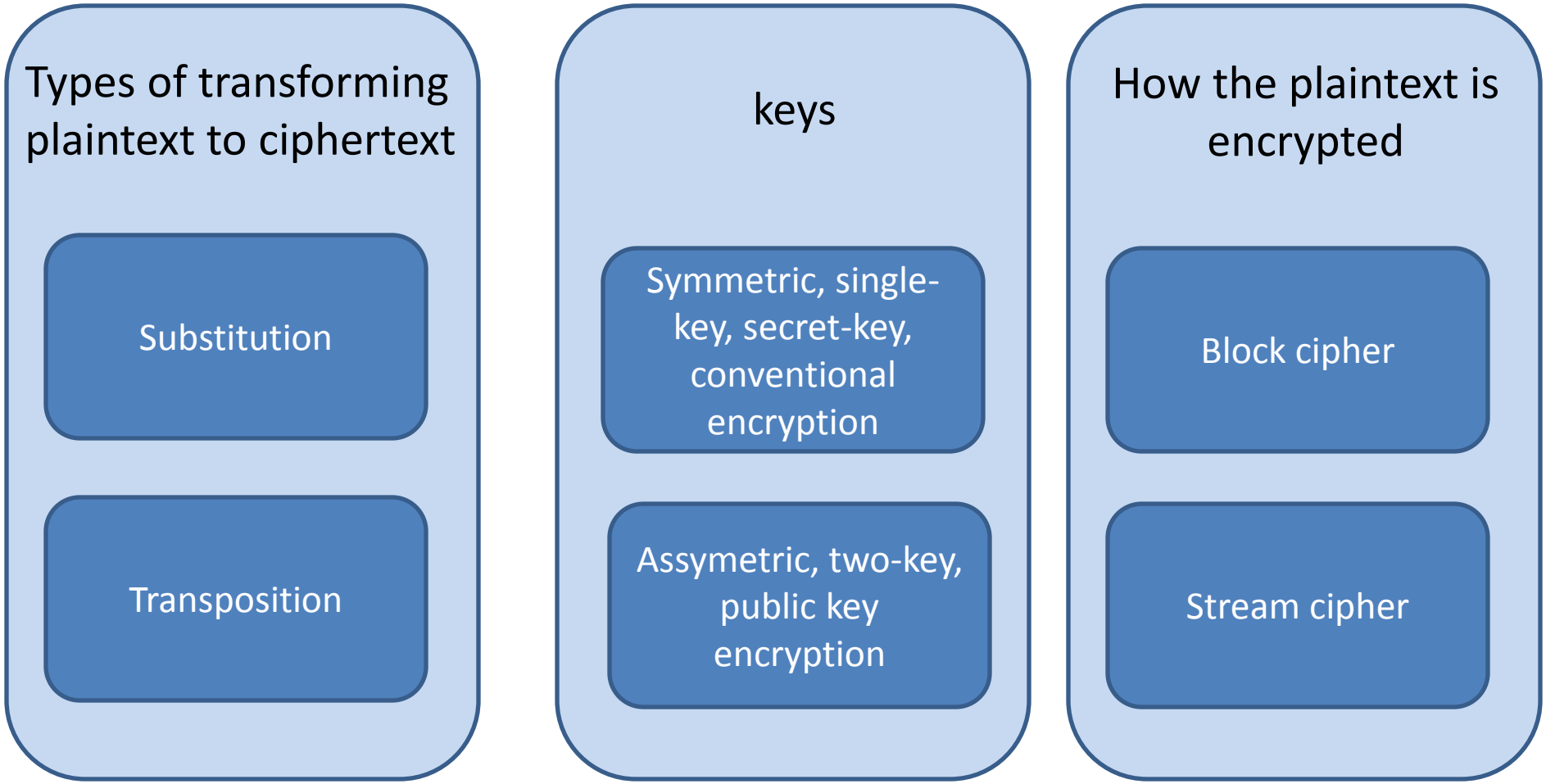
Simplified Model of Conventional Encryption



Model of Symmetric Cryptosystem



Cryptographic Systems



Attacking an Encryption System

- Cryptanalysis
- Brute-force attack

Type of Attack	Known to Cryptanalyst
Ciphertext Only	• Encryption algorithm • Ciphertext
Known Plaintext	• Encryption algorithm • Ciphertext • One or more plaintext-ciphertext pairs formed with the secret key
Chosen Plaintext	• Encryption algorithm • Ciphertext • Plaintext message chosen by cryptanalyst, together with its corresponding ciphertext generated with the secret key
Chosen Ciphertext	• Encryption algorithm • Ciphertext • Ciphertext chosen by cryptanalyst, together with its corresponding decrypted plaintext generated with the secret key
Chosen Text	• Encryption algorithm • Ciphertext • Plaintext message chosen by cryptanalyst, together with its corresponding ciphertext generated with the secret key • Ciphertext chosen by cryptanalyst, together with its corresponding decrypted plaintext generated with the secret key

Encryption Scheme Security

- Unconditionally Secure
  - It is impossible for an attacker to decrypt the ciphertext, regardless of how much time he has
- Computationally Secure
  - The cost of breaking the cipher exceeds the value of the encrypted information
  - The time required to break the cipher exceeds the useful lifetime of the information

Brute-Force Attack

- Involves trying every possible key until an intelligible translation of the ciphertext into plaintext is obtained
- On average, half of all possible keys must be tried to achieve success
- To supplement the brute-force approach, some degree of knowledge about the expected plaintext is needed.

Substitution Technique

- Is one in which the letters of plaintext are replaced by other letters or by numbers or symbols
- If the plaintext is viewed as a sequence of bits, then substitution involves replacing plaintext bit patterns with ciphertext bit patterns.

Caesar Cipher

- The earliest known use of a substitution technique
- Used by Julius Caesar
- Involves replacing each letter of the alphabet with the letter standing three places further down the alphabet.
- Alphabet is wrapped around so that the letter following Z is A

Caesar Cipher Algorithm

plain: a b c d e f g h i j k l m n o p q r s t u v w x y z
cipher: D E F G H I J K L M N O P Q R S T U V W X Y Z A B C

plain: meet me after the toga party

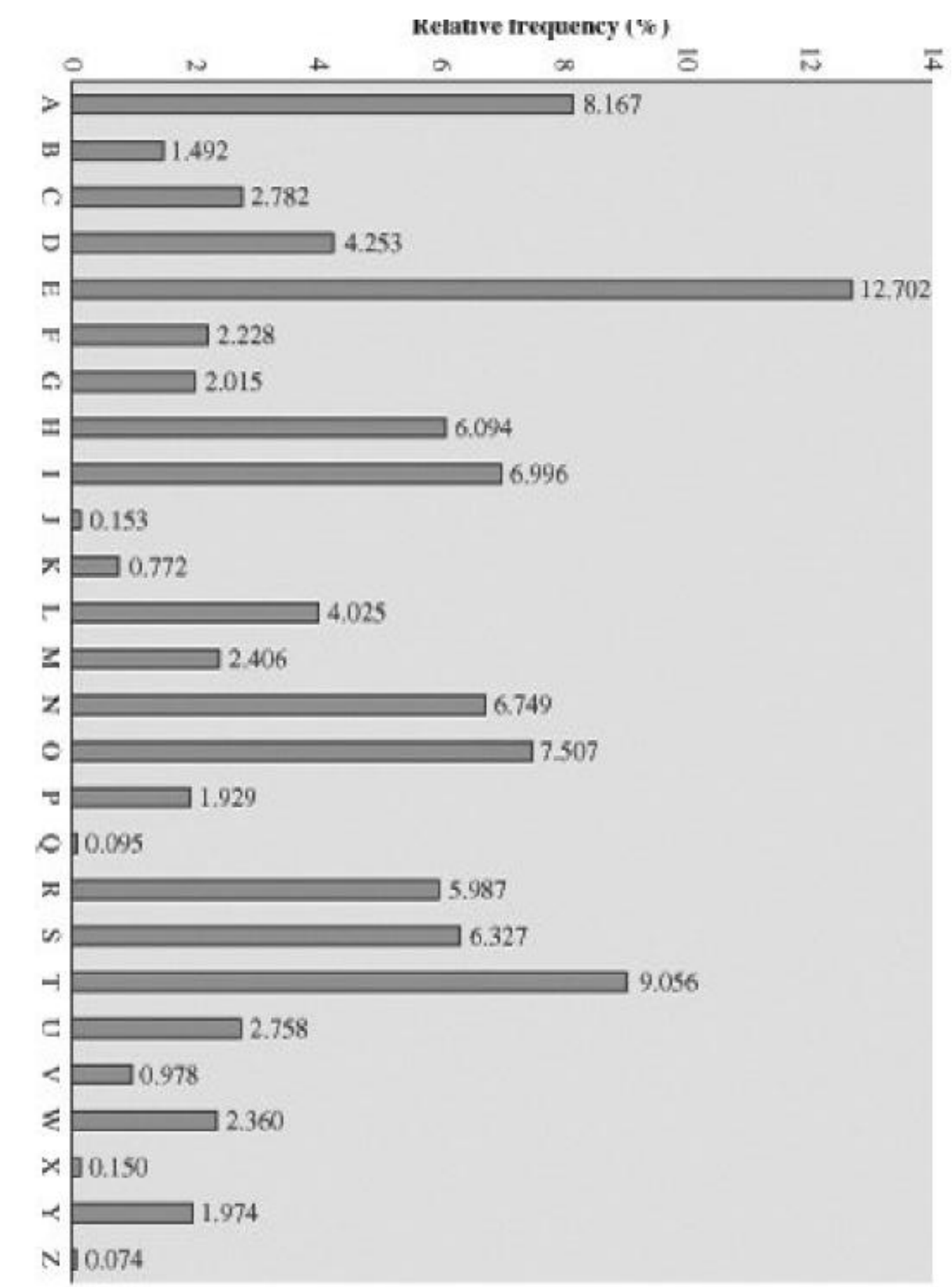
cipher: PHHW PH DIWHU WKH WRJD SDUWB

Caesar Cipher Algorithm

- Algorithm can be expressed as: $c=E(3,p)=(p+3)\mod(26)$
- A shift may be of any amount, so that the general Caesar algorithm is: $C=E(k,p)=(p+k)\mod(26)$

Monoalphabetic Cipher

- Permutation
  - Of a finite set of elements,S is an ordered sequence of all the elements of S, with each element appearing exactly once
- If the “cipher” line can be any permutation of the 26 alphabetic characters, then there are 26! Or greater than $4x10^{26}$ possible keys.


Relative frequency (%)
0
2
4
6
8
10
12
14
A 8.167
B 1.492
C 2.782
D 4.253
E 12.702
F 2.228
G 2.015
H 6.094
I 6.996
J 0.153
K 0.772
L 4.025
M 2.406
N 6.749
O 7.507
P 1.929
Q 0.095
R 5.987
S 6.327
T 9.056
U 2.758
V 0.978
W 2.360
X 0.150
Y 1.974
Z 0.074

Polyalphabetic Ciphers

- Polyalphabetic substitution cipher
  - Improves on the simple monoalphabetic technique by using different monoalphabetic substitutions as one proceeds through the plaintext message

Vigenere Cipher

- Best known and one of the simplest polyalphabetic substitution ciphers
- In this scheme the set of related monoalphabetic substitution rules consists of the 26 Caesar ciphers with shifts of 0 through 25
- To aid in understanding the scheme and to aid in its use, a matrix known as the Vigenère tableau is constructed. Each of the 26 ciphers is laid out horizontally, with the key letter for each cipher to its left. The process of encryption is simple: Given a key letter *x* and a plaintext letter y, the ciphertext letter is at the intersection of the row labeled *x* and the column labeled y.

Key	Plaintext																									
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**	**w**	**x**	**y**	**z**
a	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
b	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A
c	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B
d	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C
e	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D
f	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E
g	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F
h	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G
i	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H
j	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I
k	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J
l	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K
m	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L
n	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M
o	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N
p	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
q	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
r	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
s	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
t	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
u	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
v	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
w	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
x	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
y	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
z	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y

Vigenere Cipher Example

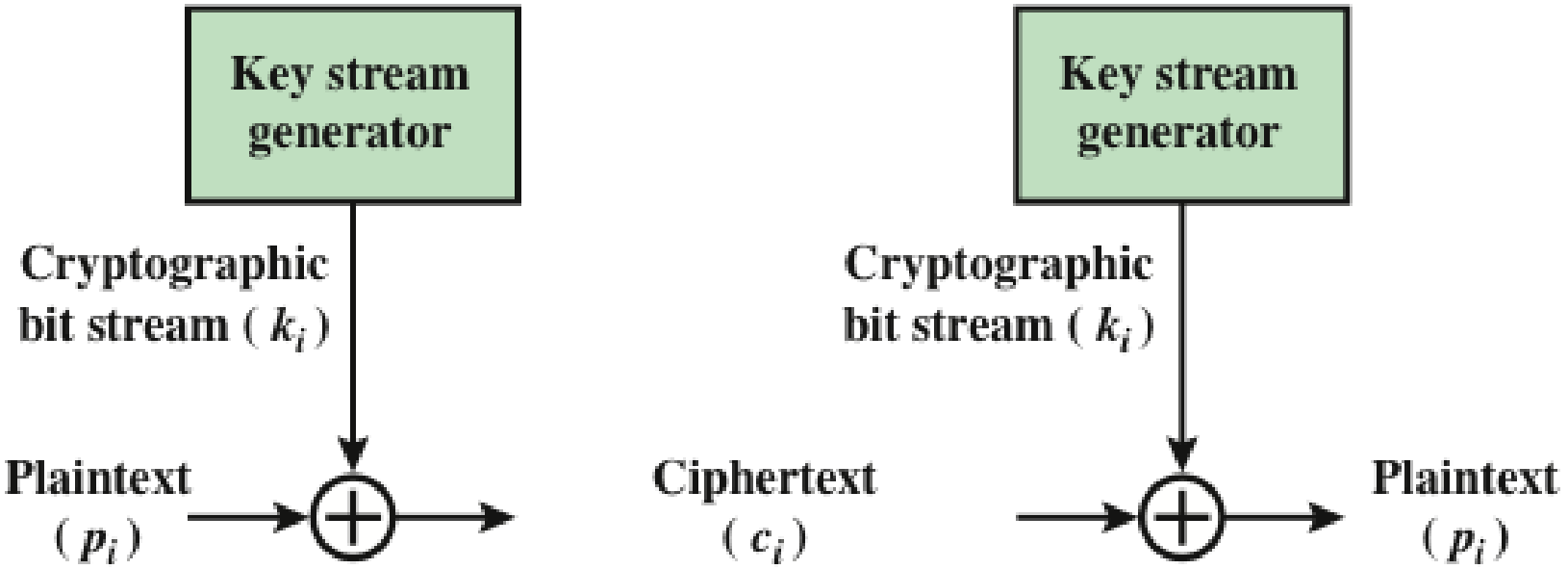
- To encrypt a message, a key is needed that is as long as the message
- Usually the key is a repeating word.
- For example, if the keyword is deceptive, the message “we are discovered save yourself” is encrypted as:

key: deceptivedeceptivedeceptive

plaintext: wearediscoveredsaveyourself

ciphertext: ZICVTWQNGRZGVTWAVZHCQYGLMGJ

Vernam Cipher



One-Time Pad

- Improvement to Vernam cipher proposed by an Army Signal Corp officer, Joseph Mauborgne
- Use a random key that is as long as the message so that the key need not be repeated
- Key is used to encrypt and decrypt a single message and then is discarded
- Each new message requires a new key of the same length as the new message
- Scheme is unbreakable
  - Produces random output that bears no statistical relationship to the plaintext
  - Because the ciphertext contains no information whatsoever about the plaintext, there is simply no way to break the code

Difficulties

- The one-time pad offers complete security but, in practice, has two fundamental difficulties:
  - There is the practical problem of making large quantities of random keys
    - Any heavily used system might require millions of random characters on a regular basis
  - Mammoth key distribution problem
    - For every message to be sent, a key of equal length is needed by both sender and receiver
- Because of these difficulties, the one-time pad is of limited utility
  - Useful primarily for low-bandwidth channels requiring very high security
- The one-time pad is the only cryptosystem that exhibits *perfect secrecy*

Rail Fence Cipher

- Simplest transposition cipher
- Plaintext is written down as a sequence of diagonals and then read off as a sequence of rows
- To encipher the message “meet me after the toga party” with a rail fence of depth 2, we would write:

m e m a t r h t g p r y

e t e f e t e o a a t

Encrypted message is:

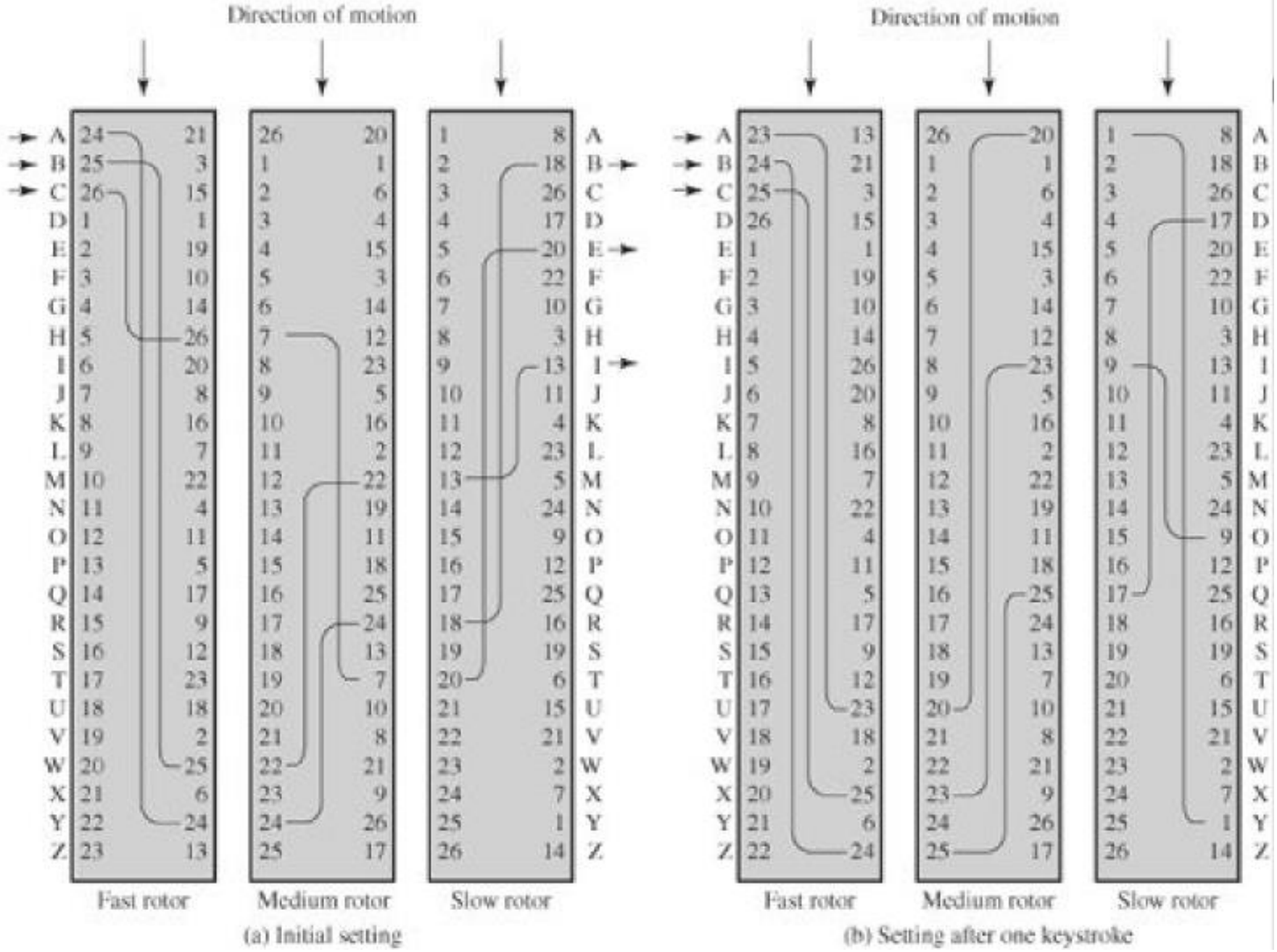
MEMATRHTGPRYETEFETEOAA

Rotor Machine (1)

- The machine consists of a set of independently rotating cylinders through which electrical pulses can flow.
- Each cylinder has 26 input pins and 26 output pins, with internal wiring that connects each input pin to a unique output pin
- Consider a machine with a single cylinder. After each input key is depressed, the cylinder rotates one position, so that the internal connections are shifted accordingly. Thus, a different monoalphabetic substitution cipher is defined. After 26 letters of plaintext, the cylinder would be back to the initial position.

Rotor Machines (2)

- The power of the rotor machine is in the use of multiple cylinders, in which the output pins of one cylinder are connected to the input pins of the next.
- Consider three cylinders. For every complete rotation of the inner cylinder, the middle cylinder rotates one pin position. Finally, for every complete rotation of the middle cylinder, the outer cylinder rotates one pin position.


Direction of motion
Fast rotor
Medium rotor
Slow rotor
(a) Initial setting
Direction of motion
Fast rotor
Medium rotor
Slow rotor
(b) Setting after one keystroke