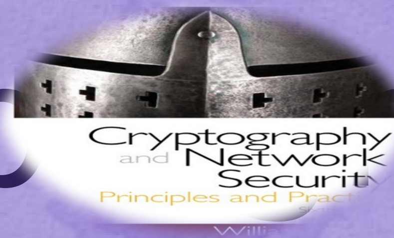
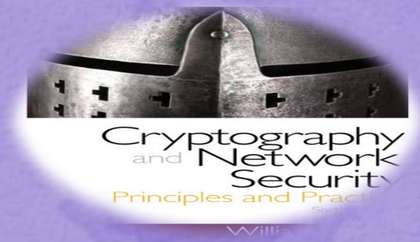


Cryptography and Network Security

Eighth Edition

by William Stallings



Chapter 3

Classical Encryption Techniques

Definitions

Plaintext
- An original message

Ciphertext
- The coded message

Enciphering/ encryption
- The process of converting from plaintext to ciphertext

Deciphering/ decryption
- Restoring the plaintext from the ciphertext

Cryptography
- The area of study of the many schemes used for encryption

Cryptographic system/cipher
- A scheme

Cryptanalysis
- Techniques used for deciphering a message without any knowledge of the enciphering details

Cryptology
- The areas of cryptography and cryptanalysis

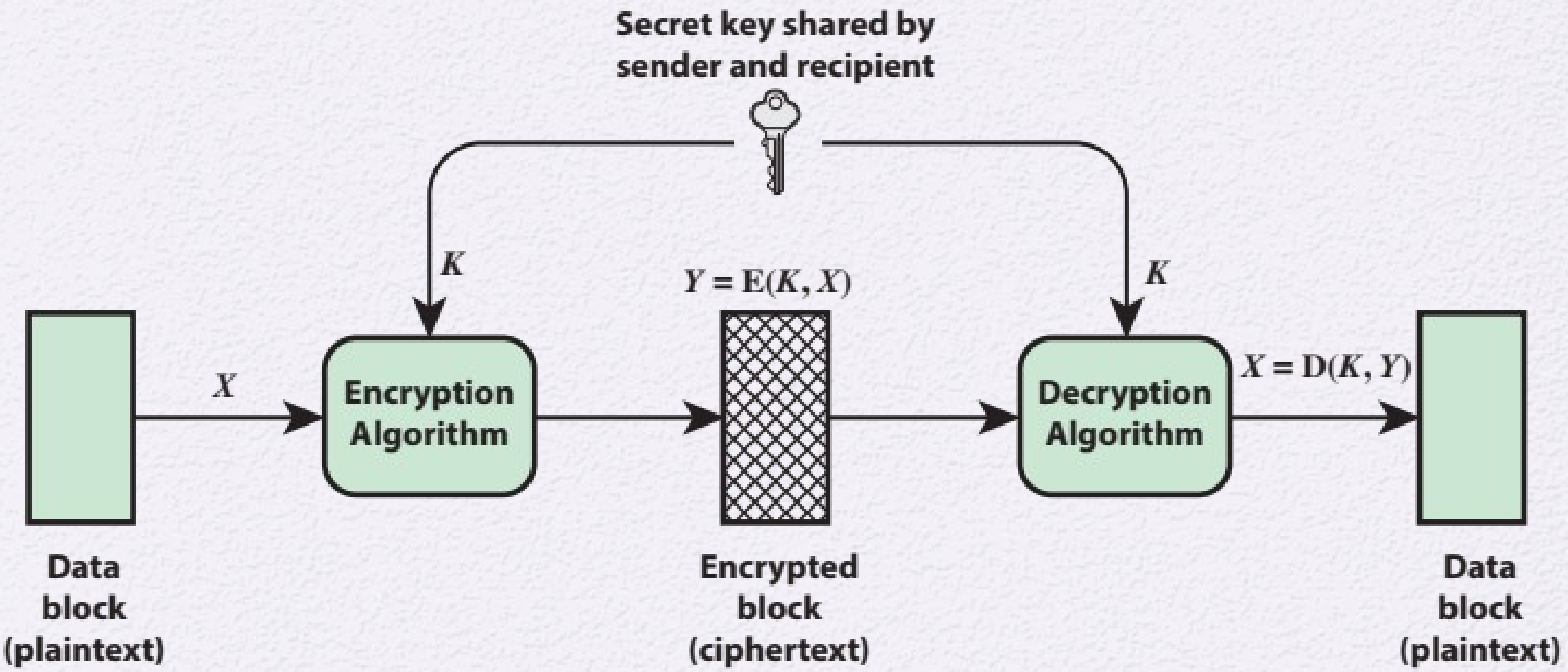
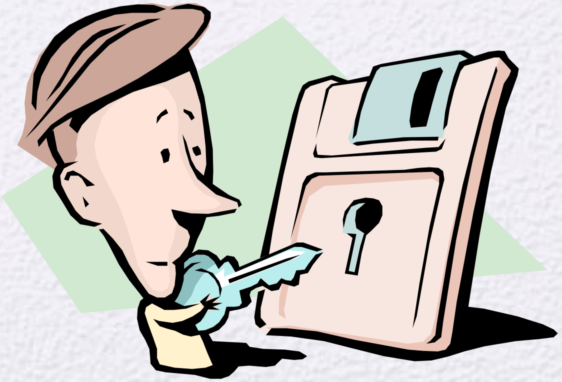


Figure 3.1 Simplified Model of Symmetric Encryption

Symmetric Cipher Model

- There are two requirements for secure use of conventional encryption:
  - A strong encryption algorithm
  - Sender and receiver must have obtained copies of the secret key in a secure fashion and must keep the key secure



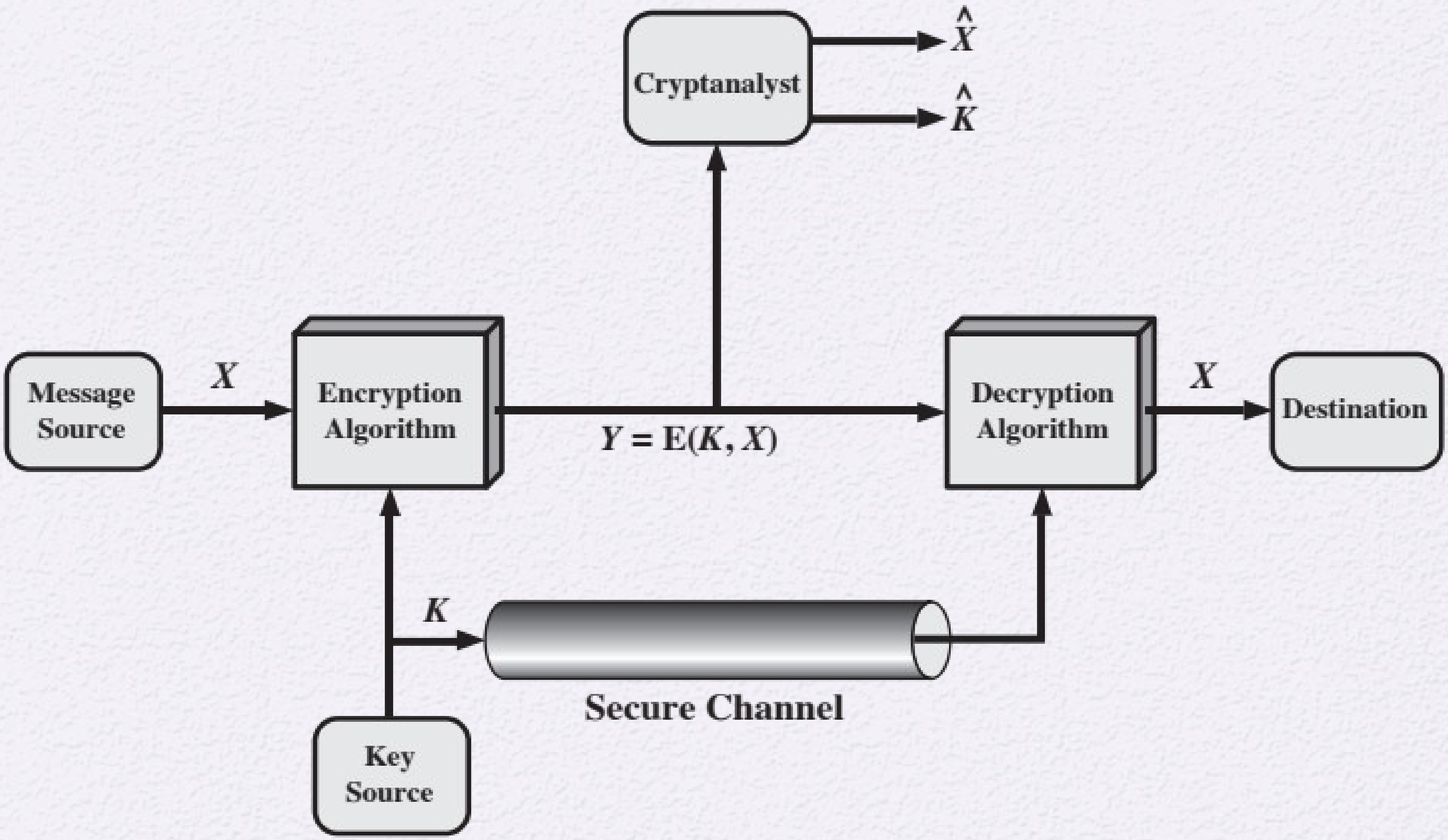


Figure 3.2 Model of Symmetric Cryptosystem

Cryptographic Systems

- Characterized along three independent dimensions:

The type of operations used for transforming plaintext to ciphertext	The number of keys used	The way in which the plaintext is processed
Substitution	Symmetric, single-key, secret-key, conventional encryption	Block cipher
Transposition	Asymmetric, two-key, or public-key encryption	Stream cipher

Cryptanalysis and Brute-Force Attack

Cryptanalysis

- Attack relies on the nature of the algorithm plus some knowledge of the general characteristics of the plaintext
- Attack exploits the characteristics of the algorithm to attempt to deduce a specific plaintext or to deduce the key being used

Brute-force attack

- Attacker tries every possible key on a piece of ciphertext until an intelligible translation into plaintext is obtained
- On average, half of all possible keys must be tried to achieve success

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

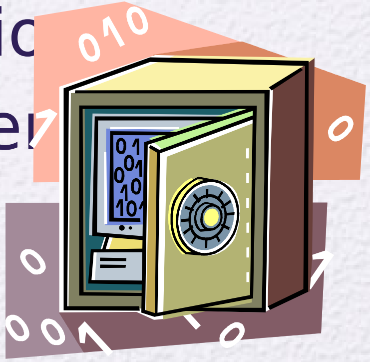
Table 3.1

Types of Attacks on Encrypted Messages

(Table is on page 68 in the textbook)

Encryption Scheme Security

- Unconditionally secure
  - No matter how much time an opponent has, it is impossible for him or her to decrypt the ciphertext simply because the required information is not there
- 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, and some means of automatically distinguishing plaintext from garble is also needed

Strong Encryption

- The term *strong encryption* refers to encryption schemes that make it impractically difficult for unauthorized persons or systems to gain access to plaintext that has been encrypted
- Properties that make an encryption algorithm strong are:
  - Appropriate choice of cryptographic algorithm
  - Use of sufficiently long key lengths
  - Appropriate choice of protocols
  - A well-engineered implementation
  - Absence of deliberately introduced hidden flaws

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

- Simplest and earliest known use of a substitution cipher
- 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

plain:	meet	me	after	the	toga	party
cipher:	PHHW	PH	DIWHU	WKH	WRJD	SDUWB

Caesar Cipher Algorithm

- Can define transformation as:

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
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

- Mathematically give each letter a number

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
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

- Algorithm can be expressed as:

  $c = \mathrm{E}(3, p) = (p + 3) \bmod (26)$

- A shift may be of any amount, so that the general Caesar algorithm is:

  $C = E(k, p) = (p + k) \bmod 26$

- Where k takes on a value in the range 1 to 25; the decryption algorithm is simply:

  $p = D(k, C) = (C - k) \bmod 26$

Figure 3.3

Brute-Force Cryptanalysis of Caesar Cipher

(This chart can be found on page 71 in the textbook)

KEY	PHHW	PH	DIWHU	WKH	WRJD	SDUWB
1	oggv	og	chvgt	vjg	vqic	rctva
2	nffu	nf	bgufs	uif	uphb	qbsuz
3	meet	me	after	the	toga	party
4	ldds	ld	zesdq	sgd	snfz	ozqsx
5	kccr	kc	ydrcp	rfc	rmey	nyprw
6	jbbq	jb	xcqbo	qeb	qldx	mxoqv
7	iaap	ia	wbpan	pda	pkcw	lwnpu
8	hzzo	hz	vaozm	ocz	ojbv	kvmot
9	gyyn	gy	uznyl	nby	niau	julns
10	fxxm	fx	tymxk	max	mhzt	itkmr
11	ewwl	ew	sxlwj	lzw	lgys	hsjlq
12	dvvk	dv	rwkvi	kyv	kfxr	grikp
13	cuuj	cu	qvjuh	jxu	jewq	fqhjo
14	btti	bt	puitg	iwt	idvp	epgin
15	assh	as	othsf	hvs	hcuo	dofhm
16	zrrg	zr	nsgre	gur	gbtn	cnegl
17	yqqf	yq	mrfqd	ftq	fasm	bmdfk
18	xppe	xp	lqepc	esp	ezrl	alcej
19	wood	wo	kpdob	dro	dyqk	zkbdi
20	vnnc	vn	jocna	cqn	cxpj	yjach
21	ummb	um	inbmz	bpm	bwoi	xizbg
22	tlla	tl	hmaly	aol	avnh	whyaf
23	skkz	sk	glzkx	znk	zumg	vgxze
24	rjjy	rj	fkyjw	ymj	ytlf	ufwyd
25	qiix	qi	ejxiv	xli	xske	tevxc

Figure 3.3 Brute-Force Cryptanalysis of Caesar Cipher

Sample of Compressed Text

```
˜+Wµ"— Ω–O)≤4{∞‡¸ ë~Ω%ràu·¯Í ◊¯Z–
Ú≠2Ò#Åæ∂ œ«q7¸Ωn·®3N◊Ú ŒzʼY–ƒ∞Í[±Û_ èΩ,<NO¬±«ˇxã  Åä£èü3Å
x}ö§kºÂ
_yÍ ˆ∆É] ˛¤ J/˚iTê&ı 'c<uΩ–
 ÄD(G WÄC~y_ïõÄW PÔı«ÎÜ†ç],¤¡ˇÌˆüÑπˇ≈ˇLˇ9Ogfl0ˇ&Œ≤ ¬≤ ØÔ§˝:
 ˇŒ!SGqèvoˆ ú\¸S>h<–*6ø‡%x´˝|fiÓ#≈˜my‰ˇ≥ñP‹,ƒi Áj  Å◊¿˝Zù–
Ω¨Õ¯6Œÿ{% „ΩÊó ¸ï π÷ÁÎ˚úO2çSÿ´O–
2Äfißi /@ˆ˝∏Kºª PŒπ¸úéˆ´3∑˘öˇÔZÌ“Y¬ŸΩœY› Ω+eô/˙‹K£¿*÷˜"≤û˜
B ZøK˜Qßÿüƒ˛!ÒflÎzsS/]›ÈQ ü
```

Figure 3.4 Sample of Compressed Text

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 4 x 10^{26} possible keys
  - This is 10 orders of magnitude greater than the key space for DES
  - Approach is referred to as a *monoalphabetic substitution cipher* because a single cipher alphabet is used per message

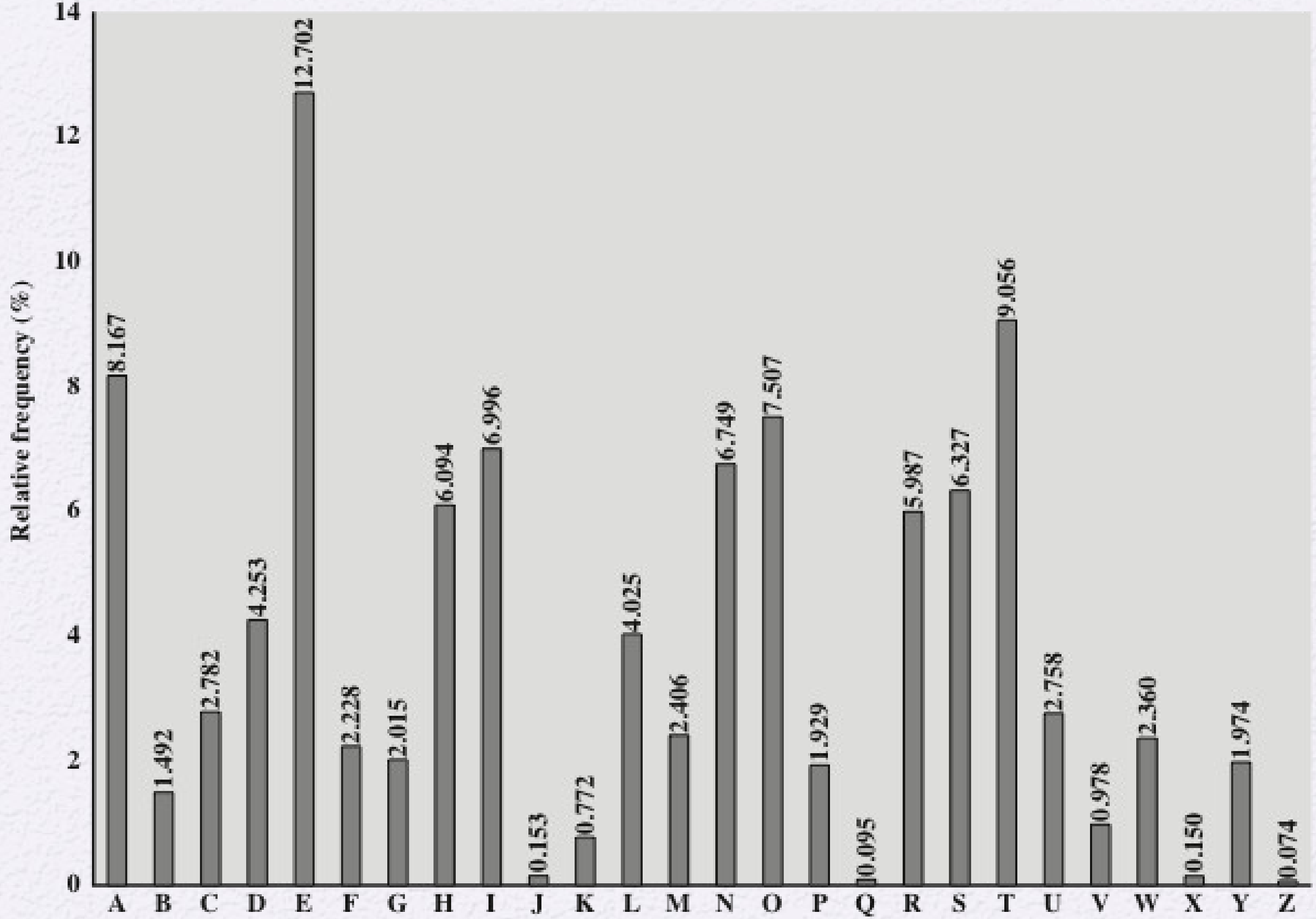
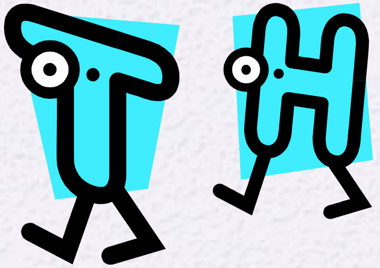


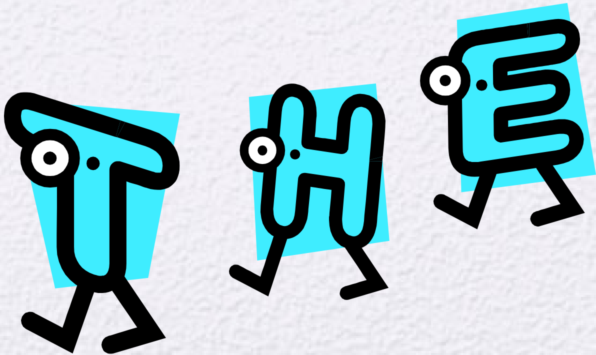
Figure 3.5 Relative Frequency of Letters in English Text

Monoalphabetic Ciphers

- Easy to break because they reflect the frequency data of the original alphabet
- Countermeasure is to provide multiple substitutes (homophones) for a single letter
- Digram
  - Two-letter combination
  - Most common is *th*



- Trigram
  - Three-letter combination
  - Most frequent is *the*



Playfair Cipher

- Best-known multiple-letter encryption cipher
- Treats digrams in the plaintext as single units and translates these units into ciphertext digrams
- Based on the use of a 5 x 5 matrix of letters constructed using a keyword
- Invented by British scientist Sir Charles Wheatstone in 1854
- Used as the standard field system by the British Army in World War I and the U.S. Army and other Allied forces during World War II

Playfair Key Matrix

- Fill in letters of keyword (minus duplicates) from left to right and from top to bottom, then fill in the remainder of the matrix with the remaining letters in alphabetic order
- Using the keyword MONARCHY:

M	O	N	A	R
C	H	Y	B	D
E	F	G	I/J	K
L	P	Q	S	T
U	V	W	X	Z

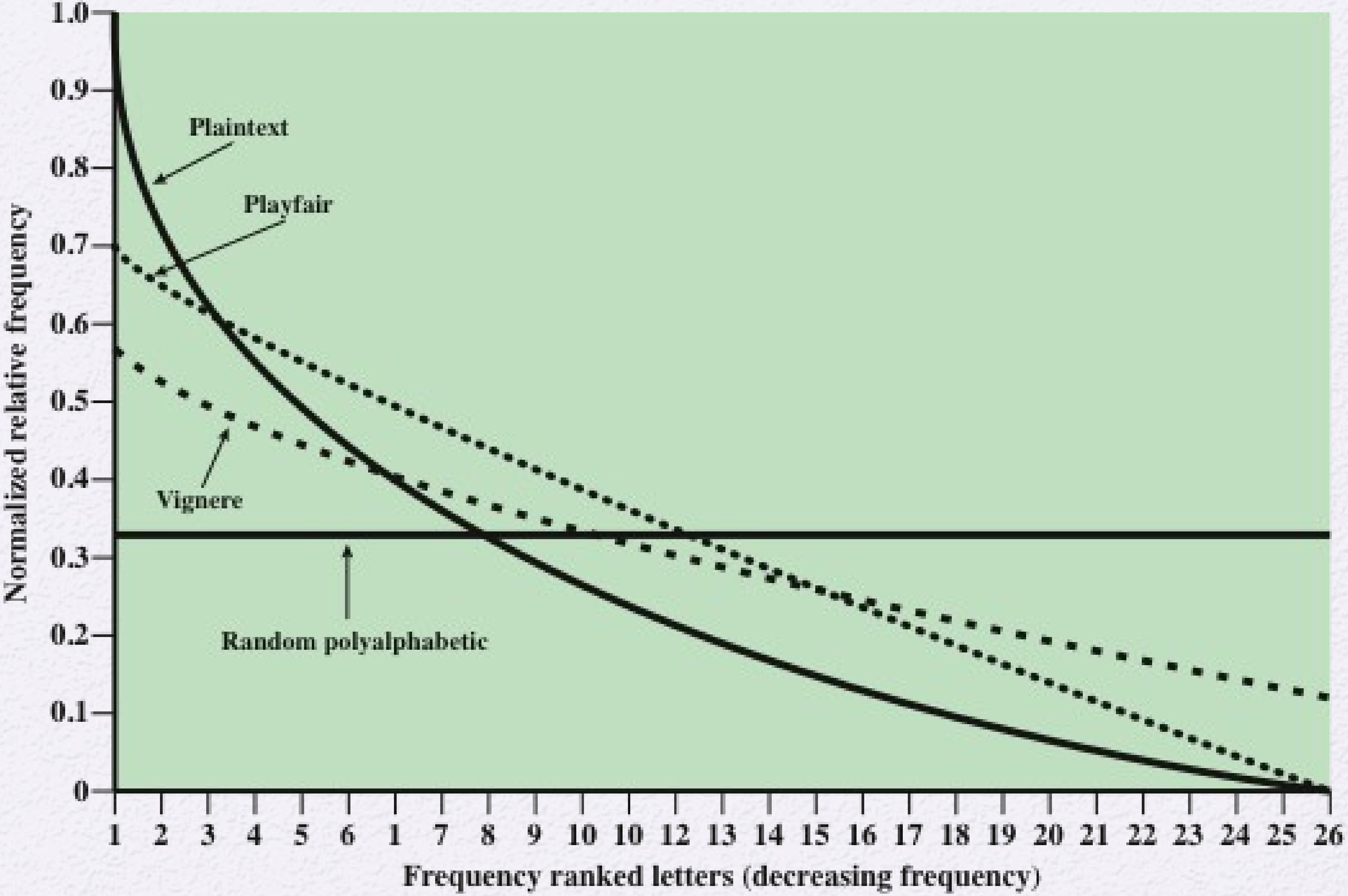


Figure 3.6 Relative Frequency of Occurrence of Letters

Hill Cipher

- Developed by the mathematician Lester Hill in 1929
- Strength is that it completely hides single-letter frequencies
  - The use of a larger matrix hides more frequency information
  - A 3 x 3 Hill cipher hides not only single-letter but also two-letter frequency information
- Strong against a ciphertext-only attack but easily broken with a known plaintext attack

Polyalphabetic Ciphers

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

All these techniques have the following features in common:
• A set of related monoalphabetic substitution rules is used • A key determines which particular rule is chosen for a given transformation

Vigenère 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
- Each cipher is denoted by a key letter which is the ciphertext letter that substitutes for the plaintext letter a

Example of Vigenère Cipher

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

key: deceptivedeceptivedeceptive
plaintext: wearediscoveredsaveyourself
ciphertext: ZICVTWQNGRZGVTWAVZHCQYGLMGJ

Vigenère Autokey System

- A keyword is concatenated with the plaintext itself to provide a running key
- Example:

  key: deceptivewearediscoveredsav

  plaintext: wearediscoveredsaveyourself

  ciphertext: ZICVTWQNGKZEIIGASXSTSLVVWLA
- Even this scheme is vulnerable to cryptanalysis
  - Because the key and the plaintext share the same frequency distribution of letters, a statistical technique can be applied

Vernam Cipher

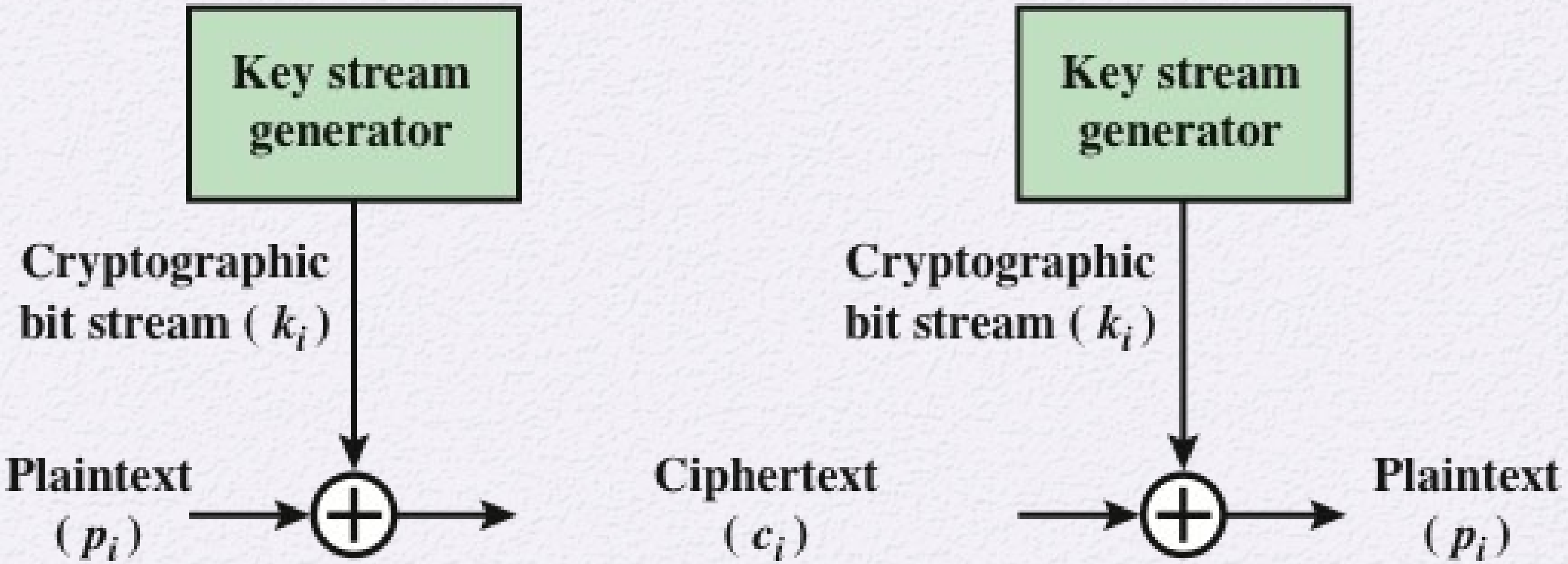


Figure 3.7 Vernam Cipher

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* (see Appendix F)

Rail Fence Cipher

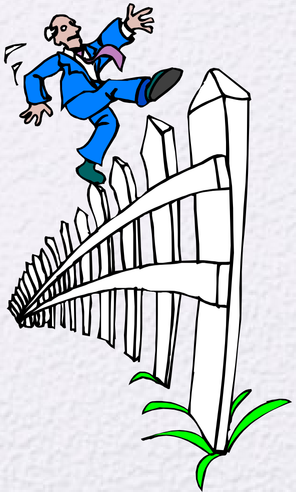
- Simplest transposition cipher
- Plaintext is written down as a sequence of diagonals and then read off as a sequence of rows
- To encipher the message “meet me after the toga party” with a rail fence of depth 2, we would write:

  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:

  MEMATRHTGPRYETEFETEOAAT



Row Transposition Cipher

- Is a more complex transposition
- Write the message in a rectangle, row by row, and read the message off, column by column, but permute the order of the columns
  - The order of the columns then becomes the key to the algorithm

    Key: 4 3 1 2 5 6 7

    Plaintext: a t t a c k p

    o s t p o n e

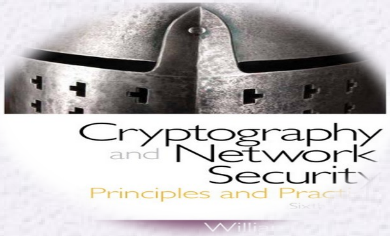
    d u n t i l t

    w o a m x y z

    Ciphertext: TTNAAPTMTSUOAODWCOIXKNLYPETZ

Summary

- Present an overview of the main concepts of symmetric cryptography
- Explain the difference between cryptanalysis and brute-force attack
- Understand the operation of a monoalphabetic



- Understand the operation of a polyalphabetic cipher
- Present an overview of the Hill cipher