

GLOBAL
EDITION

Cryptography and Network Security

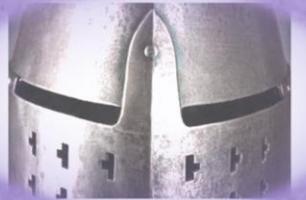
Principles and Practice

SEVENTH EDITION

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Pearson



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

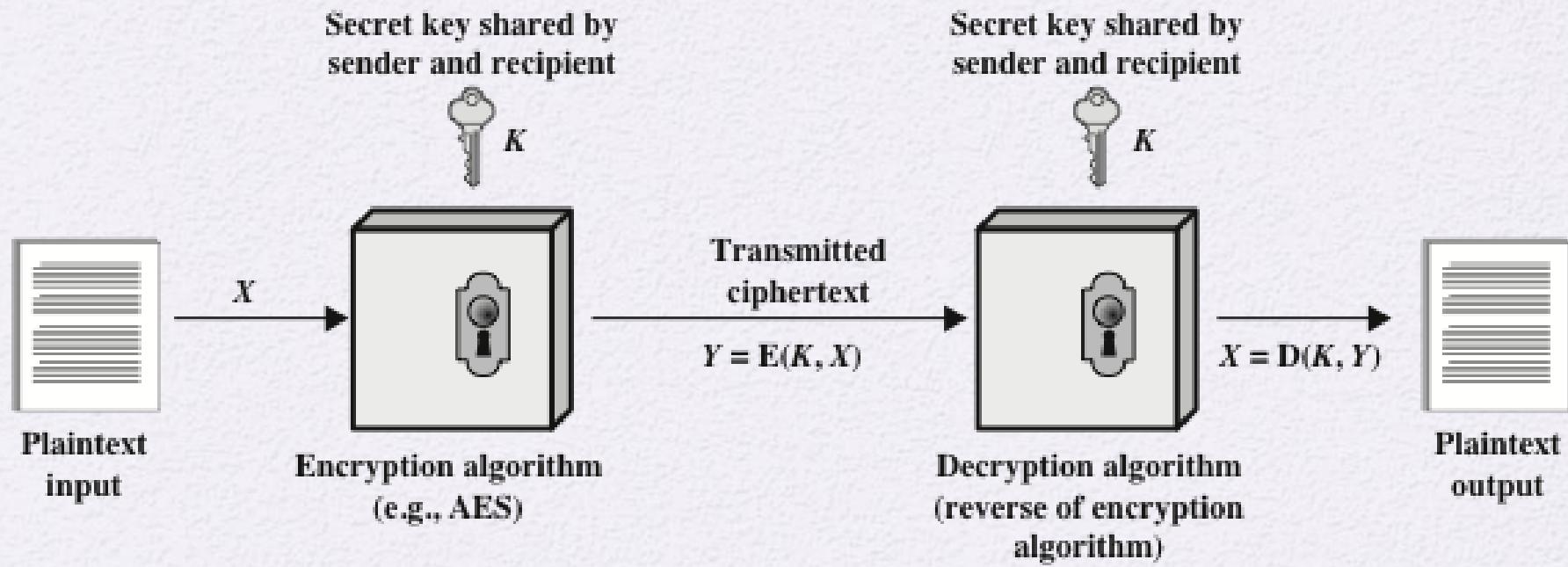


Figure 3.1 Simplified Model of Symmetric Encryption

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



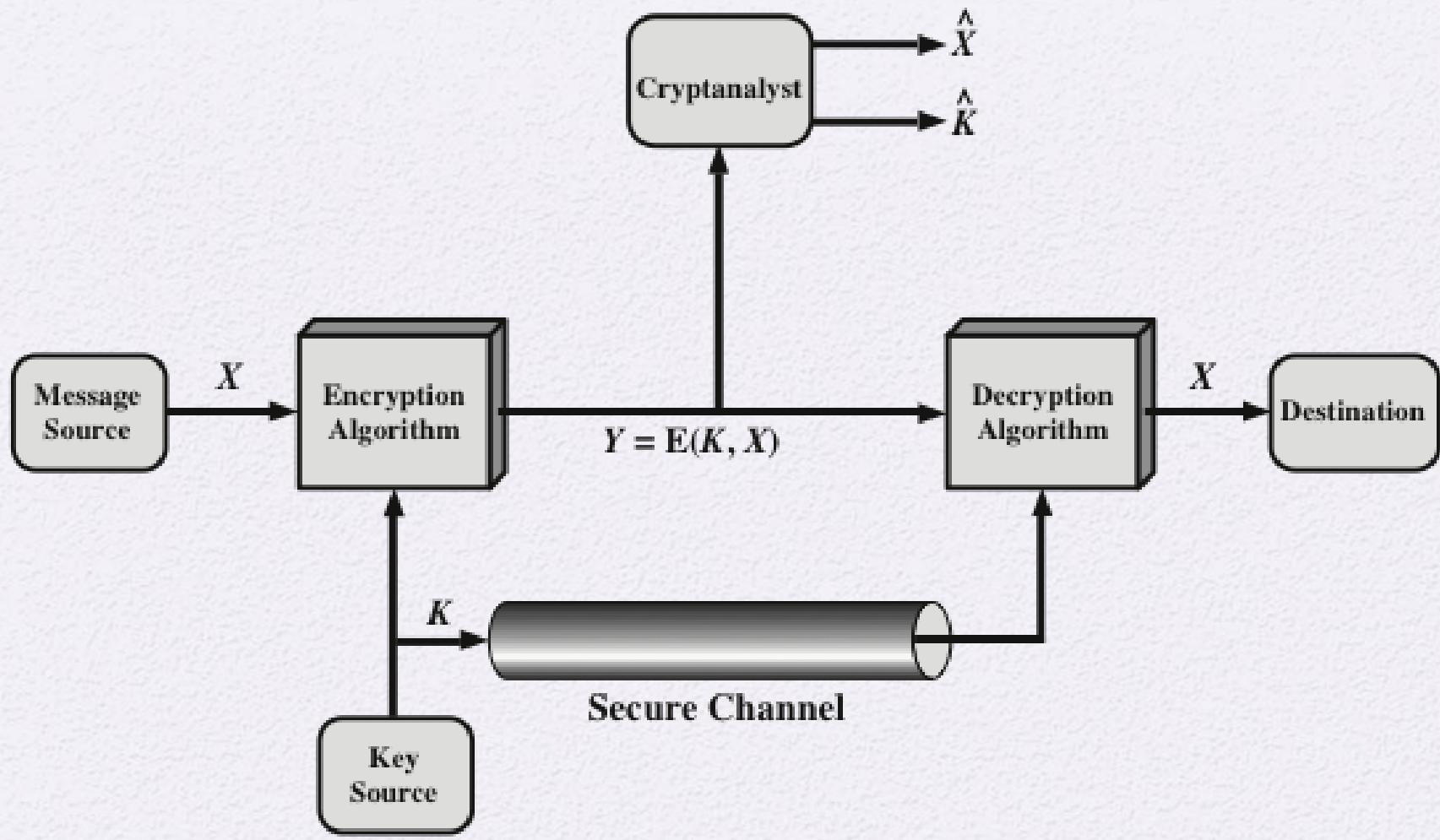


Figure 3.2 Model of Symmetric Cryptosystem

Cryptographic Systems

- Characterized along three independent dimensions:

The type of operations used for transforming plaintext to ciphertext

Substitution

Transposition

The number of keys used

Symmetric,
single-key, secret-key,
conventional
encryption

Asymmetric, two-key,
or public-key
encryption

The way in which the plaintext is processed

Block cipher

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

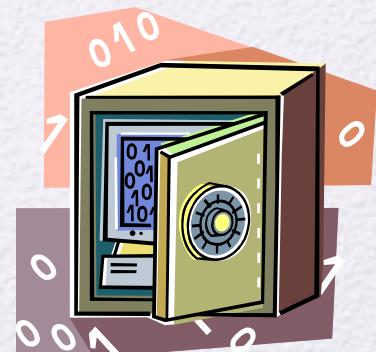
- Attacker tries every possible key on a piece of ciphertext until an intelligible translation into plaintext is obtained
- On average, half of all possible keys must be tried to achieve success

Table 3.1
Types of Attacks on Encrypted Messages

Type of Attack	Known to Cryptanalyst
Ciphertext Only	<ul style="list-style-type: none"> • Encryption algorithm • Ciphertext
Known Plaintext	<ul style="list-style-type: none"> • Encryption algorithm • Ciphertext • One or more plaintext-ciphertext pairs formed with the secret key
Chosen Plaintext	<ul style="list-style-type: none"> • Encryption algorithm • Ciphertext • Plaintext message chosen by cryptanalyst, together with its corresponding ciphertext generated with the secret key
Chosen Ciphertext	<ul style="list-style-type: none"> • Encryption algorithm • Ciphertext • Ciphertext chosen by cryptanalyst, together with its corresponding decrypted plaintext generated with the secret key
Chosen Text	<ul style="list-style-type: none"> • 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

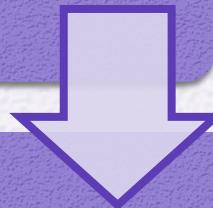
Encryption Scheme Security

- Unconditionally secure
 - 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

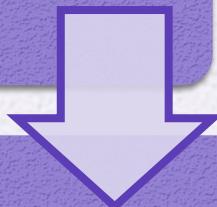


Brute-Force Attack

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

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:

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

$$\begin{aligned} c &= E(3, p) = (p + 3) \bmod 26 \\ &= (p + 3) \bmod 26 \\ &= 6 \bmod 26 \end{aligned}$$

$$\begin{aligned} &\text{A mod } B \\ &(A - A) \div (B \times B) \\ &6 - 6 \div 26 \end{aligned}$$

In base mode

- 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:

$$\begin{aligned} p &= D(k, C) = (C - k) \bmod 26 \\ &= (g - 3) \bmod 26 \\ &= (g - 3) \bmod 26 \\ &= 3 \bmod 26 \rightarrow ③ \end{aligned}$$

Figure 3.3

Brute-Force Cryptanalysis of Caesar Cipher

(This chart can be found on page 75 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 ydrctp 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	vnnnc 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

Monoalphabetic Cipher

$$\begin{aligned} S &= \{1, 2, 3, 4\} \\ &\boxed{2^4 = 16} \end{aligned}$$

- 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 4×10^{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

$$\begin{aligned} 4! &= 4 \times 3 \times 2 \times 1 = 24 \\ 26! &= 25 \times 24 \times 23 \times \dots \times 1 = \end{aligned}$$

Monoalphabetic Cipher

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

[Secret writings] → KZGHNZW Q HOWOC

Plain Text	s	e	c	r	e	t		w	r	i	t	i	n	g	s
Cipher Text	K	Z	G	H	Z	W		Q	H	O	W	O	C	N	K

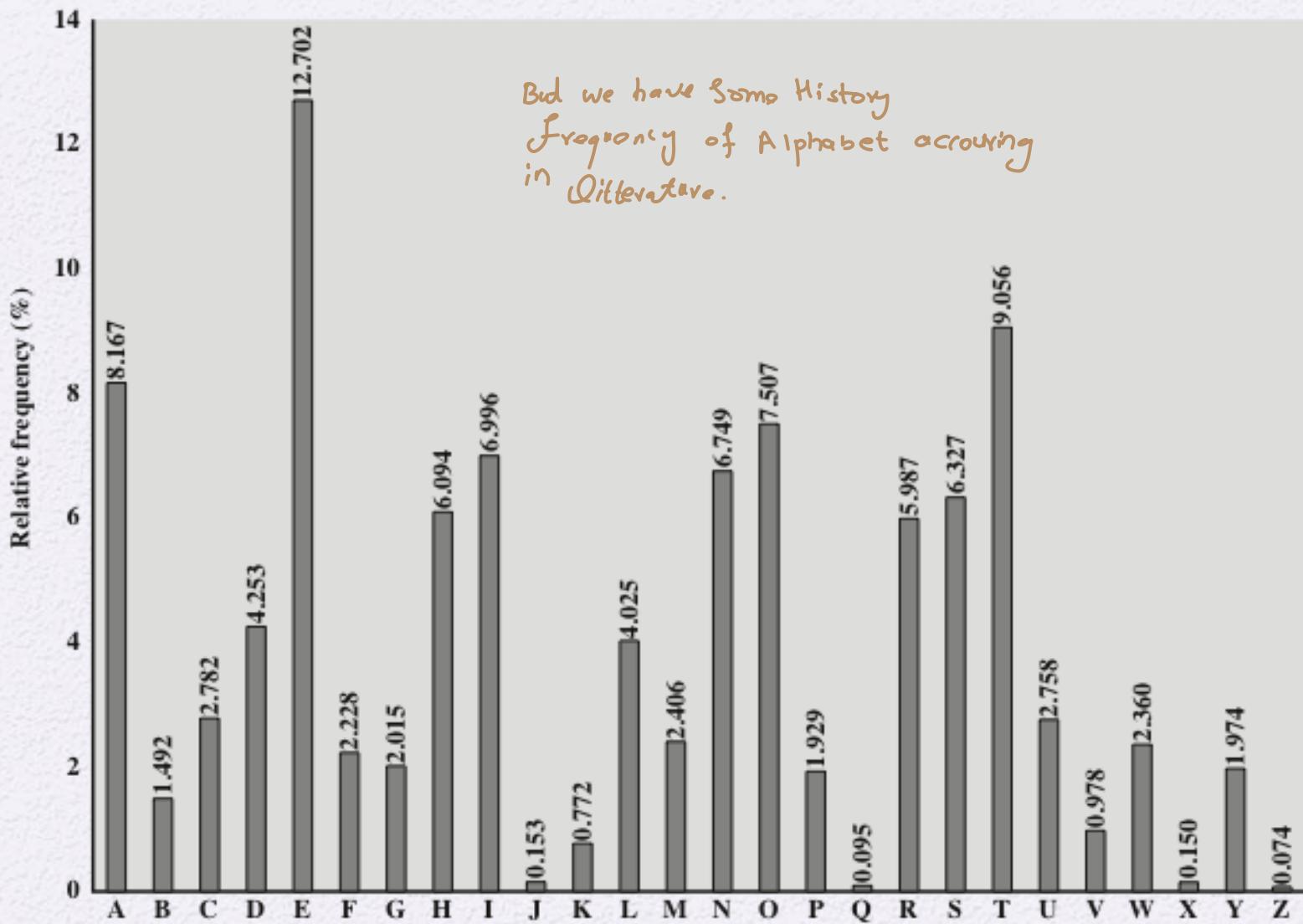


Figure 3.5 Relative Frequency of Letters in English Text

Cipher text

UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUBMETSXAI
Z VUEPHZHMDZSHZOWSFAPPDTSPQUZWYMXUZUHSX
EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ

- ① P and S → frequency
- ② letter occurring in literature
- ③ check the message created from the cipher is reasonable.

Frequency of Alphabets

P 13.33	H 5.83	F 3.33	B 1.67	C 0.00
Z 11.67	D 5.00	W 3.33	G 1.67	K 0.00
S 8.33	E 5.00	Q 2.50	Y 1.67	L 0.00
U 8.33	V 4.17	T 2.50	I 0.83	N 0.00
O 7.50	X 4.17	A 1.67	J 0.83	R 0.00
M 6.67				

Cryptanalysis

- It seems likely that cipher letters P and Z are the equivalents of plain letters e and t, but it is not certain which is which.
- The letters S, U, O, M, and H probably correspond to plain letters from the set {a, h, i, n, o, r, s}.
- Letters A, B, G, Y, I, J are likely included in the set {b, j, k, q, v, x, z}.
- After this make some tentative assignments to fill in the plain text to see if it looks like a reasonable message.
- Or certain words may be known in text or we could look for repeating sequences of cipher letters and try to deduce their plain text equivalents

UZQSOVUOHOXMOPVGPOZPEVSGZWSZOPFPESXUDBMETSXAIZ
t a e e te a that e e a a
VUEPHZHMDZSHZOWSFAPPDTSVPQUZWYMXUZUHSX
e t ta t ha e ee a e th t a
EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ
e e e tat e the t

Partial representation of the cipher text

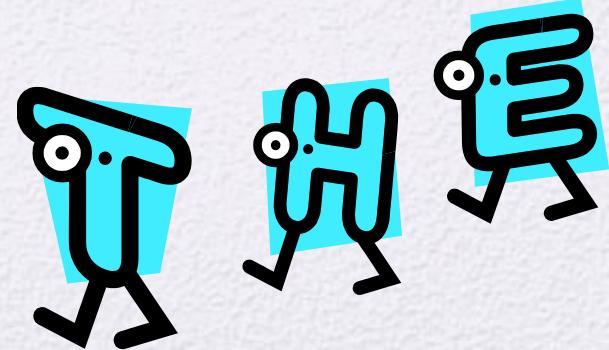
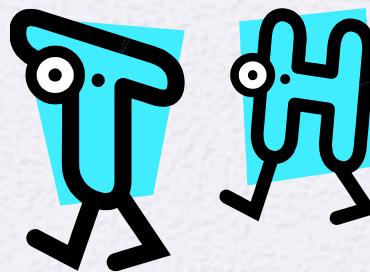
it was disclosed yesterday that several informal but direct contacts have been made with political representatives of the viet cong in moscow

Plain 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 5×5 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: $NA \rightarrow O \underline{N}$

① balloon
→ ball on
→ bangoon
→ ba → Check Matrix
↳ same col → IJ B
↳ bx → su
↳ bo
↳ fm
↳ on → NA

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

Rules for Playfair Substitution



- Repeating plaintext letters that are in the same pair are separated with a filler letter, such as x, so that balloon would be treated as ba lx lo on.
- Two plaintext letters that fall in the same row of the matrix are each replaced by the letter to the right, with the first element of the row circularly following the last. For example, ar is encrypted as RM.
- Two plaintext letters that fall in the same column are each replaced by the letter beneath, with the top element of the column circularly following the last. For example, mu is encrypted as CM.
- Otherwise, each plaintext letter in a pair is replaced by the letter that lies in its own row and the column occupied by the other plaintext letter. Thus, hs becomes BP and ea becomes IM (or JM, as the encipherer wishes).

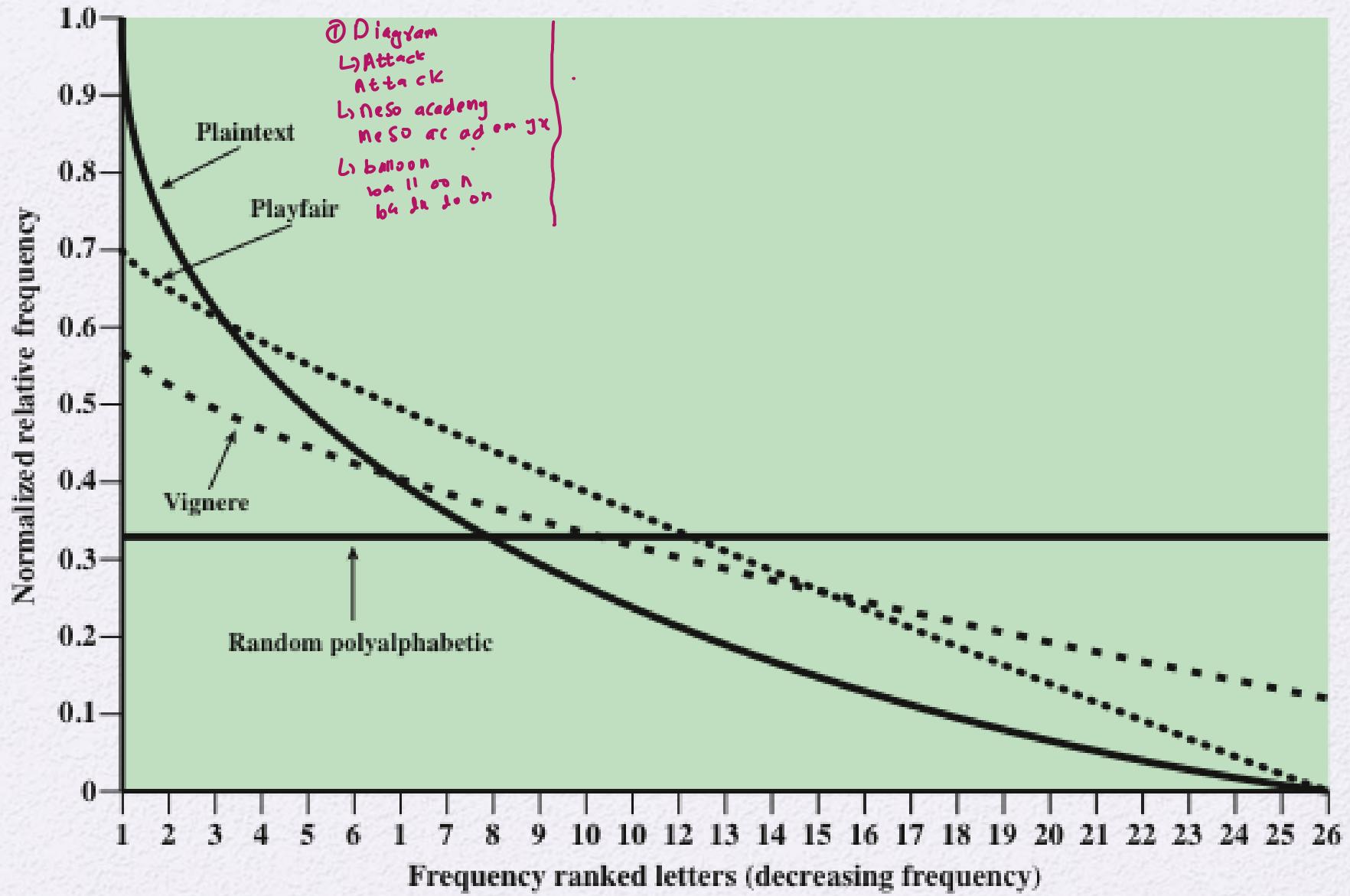


Figure 3.6 Relative Frequency of Occurrence of Letters

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

Encryption Process r^{mod}

$$L_i = (P_i + K_{i \bmod n}) \bmod 26$$

Decryption:

$$P_i = (C_i - K_{i \bmod n}) \bmod 26$$

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:

For $\rightarrow W \rightarrow (d, 3), (w, 22)$
 $w \rightarrow (3+22) \bmod 26$
 $w \rightarrow 25 \rightarrow Z$
 $w \rightarrow Z$ (exploded)

key: deceptive deceptive deceptive

plaintext: wearediscoveredsaveyourself

ciphertext: ZICVTWQNGRZGVTWAVZHCQYGLMGJ

Vigenère Autokey System

If Attack know the length
of cipher then may be
he guess the length of
the key.

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

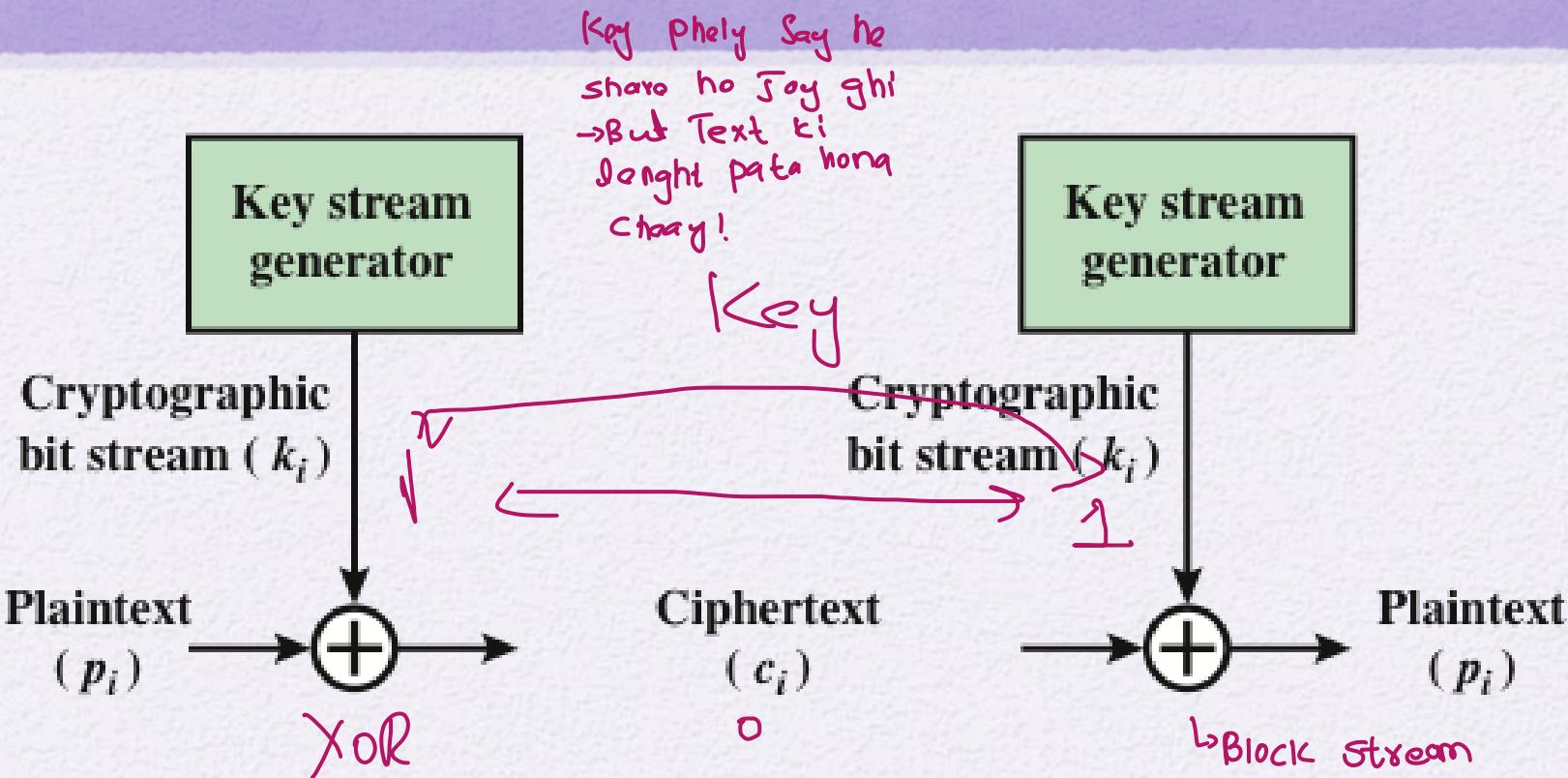
key: deceptivewearediscoveredsav

plaintext: wearediscoveredsaveyourself

ciphertext: ZICVTWQNGKZEIIGASXSTSLVVWLA

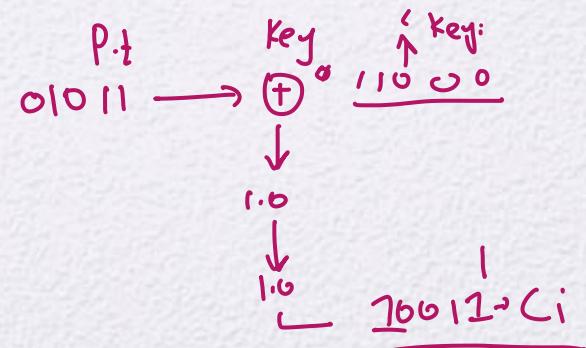
- Even this scheme is vulnerable to cryptanalysis
 - Because the key and the plaintext share the same frequency distribution of letters, a statistical technique can be applied

Vernam Cipher



x	y	XOR
0	0	0
0	1	1
1	0	1

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)

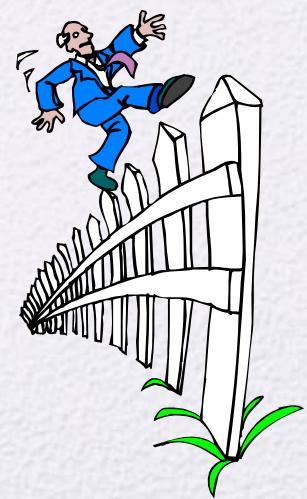
Rail Fence Cipher

- 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: TTNAAPMTSUOAODWCOIXKNLYPETZ

Steganography

3rd March

Dear George,

Greetings to all at Oxford. Many thanks for your letter and for the Summer examination package. All Entry Forms and Fees Forms should be ready for final despatch to the Syndicate by Friday 20th or at the very latest, I'm told, by the 21st. Admin has improved here, though there's room for improvement still; just give us all two or three more years and we'll really show you! Please don't let these wretched 16+ proposals destroy your basic O and A pattern. Certainly this sort of change, if implemented immediately, would bring chaos.

Sincerely yours,

A Puzzle for Inspector Morse
(from *The Silent World of Nicholas Quinn*, by Colin Dexter)

Other Steganography Techniques



- Character marking
 - Selected letters of printed or typewritten text are over-written in pencil
 - The marks are ordinarily not visible unless the paper is held at an angle to bright light
- Invisible ink
 - A number of substances can be used for writing but leave no visible trace until heat or some chemical is applied to the paper
- Pin punctures
 - Small pin punctures on selected letters are ordinarily not visible unless the paper is held up in front of a light
- Typewriter correction ribbon
 - Used between lines typed with a black ribbon, the results of typing with the correction tape are visible only under a strong light

Steganography vs. Encryption

- Steganography has a number of drawbacks when compared to encryption
 - It requires a lot of overhead to hide a relatively few bits of information
 - Once the system is discovered, it becomes virtually worthless

- The advantage of steganography
 - It can be employed by parties who have something to lose should the fact of their secret communication (not necessarily the content) be discovered
 - Encryption flags traffic as important or secret or may identify the sender or receiver as someone with something to hide

Summary

- Symmetric Cipher Model
 - Cryptography
 - Cryptanalysis and Brute-Force Attack
- Transposition techniques
- Substitution techniques
 - Caesar cipher
 - Monoalphabetic ciphers
 - Playfair cipher
 - Polyalphabetic ciphers
 - One-time pad
- Steganography

