Classical Encryption Techniques

1. Substitution Techniques
    1. Caesar Cipher
    2. Mono alphabetic Cipher
    3. Play fair Cipher
    4. Hill Cipher
    5. Polyalphabetic Cipher
    6. One-Time pad
2. Transposition Techniques
    1. Rail Fence
    2. Row Column Trasposition

Classical Substitution Ciphers

- Substitution technique is a classical encryption technique where the characters present in the original message are replaced by the other characters or numbers or by symbols.
- If the plain text (original message) is considered as the string of bits, then the substitution technique would replace bit pattern of plain text with the bit pattern of cipher text.

Caesar Cipher

- This the simplest substitution cipher by Julius Caesar.
- In this substitution technique, to encrypt the plain text, each alphabet of the plain text is replaced by the alphabet three places further it.
- And to decrypt the cipher text each alphabet of cipher text is replaced by the alphabet three places before it.
- Assign a numerical equivalent to each letter

A	B	C	D	E	F	G	H	I	J	K	L	M
0	1	2	3	4	5	6	7	8	9	10	11	12
N	O	P	Q	R	S	T	U	V	W	X	Y	Z
13	14	15	16	17	18	19	20	21	22	23	24	25

Then the algorithm can be expressed as follows. For each plaintext letter p, substitute the ciphertext letter C:[2]

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

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

$$C = \mathrm{E}(k, p) = (p + k) \bmod 26 \quad \textbf{(2.1)}$$

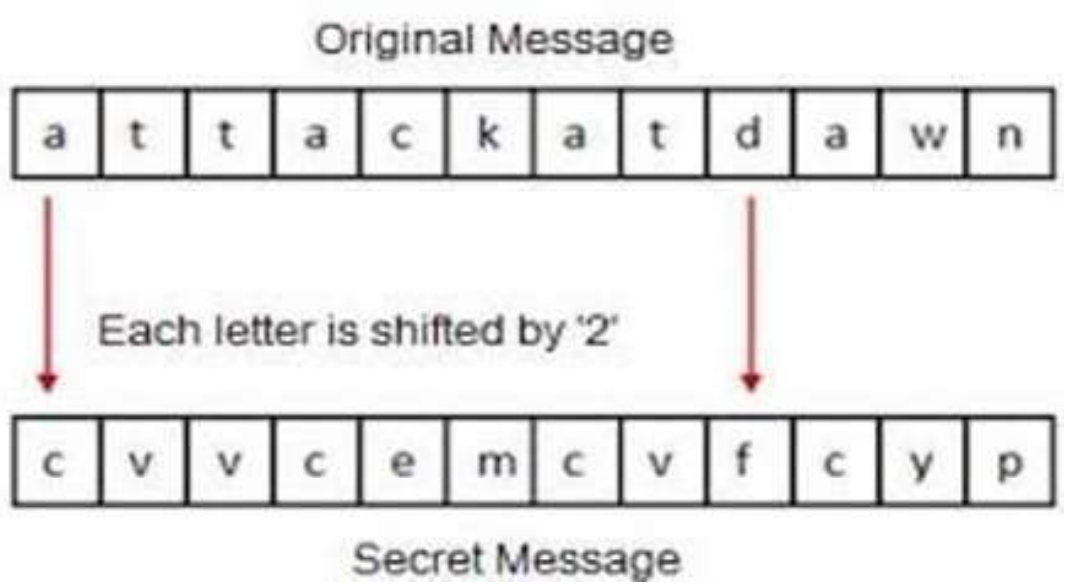
where k takes on a value in the range 1 to 25. The decryption algorithm is simply

$$p = \mathrm{D}(k, C) = (C - k) \bmod 26 \quad \textbf{(2.2)}$$

```
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
```

- Shift cipher:key=2,3,4,5.....
- Shift cipher with key value=3 is called Caesar Cipher
- Example with key = 2



Caesar cipher-Pros & cons

- Pros
  1. Simple
  2. easy to implement
- Cons
  1. The encryption and decryption algorithms are known.
  2. There are only 25 keys to try(Vulnerable to Brute Force Attack).
  3. The language of the plaintext is known and easily recognizable

Brute Force Attack in Caesar Cipher

Brute-Force Cryptanalysis of Caesar Cipher

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

Brute force attack

Ciphertext: SQDYMZK

Shifts	Back	Result
0	[26]	SQDYMZK
1	[25]	TREZNAL
2	[24]	USFAOBM
3	[23]	VTGBPCN
4	[22]	WUHCQDO
5	[21]	XVIDREP
6	[20]	YWJESFQ
7	[19]	ZXKFTGR
8	[18]	AYLGUHS
9	[17]	BZMHVIT
10	[16]	CANIWJU
11	[15]	DBOJXKV
12	[14]	ECPKYLW
13	[13]	FDQLZMX
13	[13]	FDQLZMX
14	[12]	GERMANY
15	[11]	HFSNBOZ
16	[10]	IGTOCPA
17	[9]	JHUPDQB
18	[8]	KIVQERC
19	[7]	LJWRFSD
20	[6]	MKXSGTE
21	[5]	NLYTHUF
22	[4]	OMZUIVG
23	[3]	PNAVJWH
24	[2]	QOBWKXI
25	[1]	RPCXLYJ

Monoalphabetic Cipher

- The cipher line can be any permutation of the 26 alphabetic characters
- A permutation of a finite set of elements 'S' is an ordered sequence of all the elements of S with each element appearing exactly once
- For example, if S=a,b,c , there are six permutations of : abc, acb, bac, bca, cab, cba(n! in general
- Monoalphabetic cipher would seem to eliminate brute-force techniques for cryptanalysis
- A single cipher alphabet (mapping from plain alphabet to cipher alphabet) is used per message
- English Language-Nature of plain text is known

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

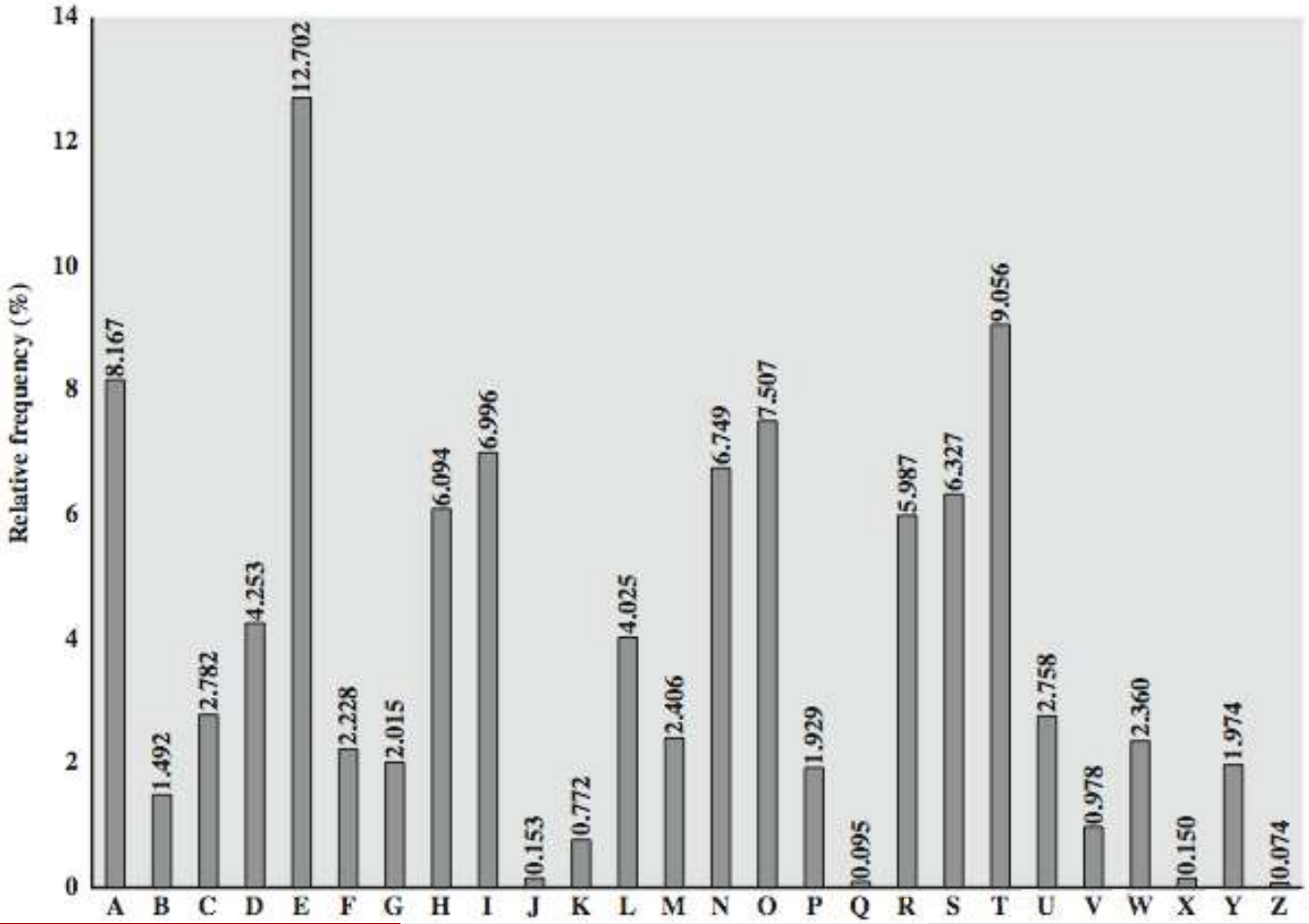
one permutation of the possible 26!

plain text : c r y p t o g r a p h y

cipher text : B S E Z W U C S J Z N E

Hence we obtain the cipher text as "BSEZWUCSJZNE"

Relative frequency of English letters



Example

CT	G	Z	G	E	W	V	G	R	N	C	P
PT	E		E				E				
PT	E		E			T	E				
PT	E		E			T	E			A	
PT	E		E			T	E		L	A	N
PT	E		E			T	E	P	L	A	N
PT	E	X	E	C	U	T	E	P	L	A	N

UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUDBMETSXAIZ
VUEPHZHMDZSHZOWSFPAPPDTSVPQUZWYMXUZUHSX
EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ

UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUDBMETSXAIZ
VUEPHZHMDZSHZOWSFPAPPDTSVPQUZWYMXUZUHSX
EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ

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				

```
UZQSOVUOHXMOPVGPOZPEVSGZWSZOPFPESXUDBMETSXAIZ
 t a          e  e te  a that e e a        a
VUEPHZHMDZSHZOWSFPAPPDTSVPQUZWYMXUZUHSX
   e t   ta t ha e ee  a e  th    t  a
EPYEPOPDZSZUFPOMBZWPFUPZHMDJUDTMOHMQ
 e  e e tat  e   the   t
```

Only four letters have been identified, but already we have quite a bit of the message. Continued analysis of frequencies plus trial and error should easily yield a solution from this point. The complete plaintext, with spaces added between words, follows:

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

Monoalphabetic Cipher-Pros & Cons

- Pros
  1. Better security than Caesar cipher
- Cons
  1. Monoaphabetic ciphers are easy to break because they reflect the frequency data of the original alphabet.
  2. countermeasure is to provide multiple substitutes, known as homophones, for a single letter

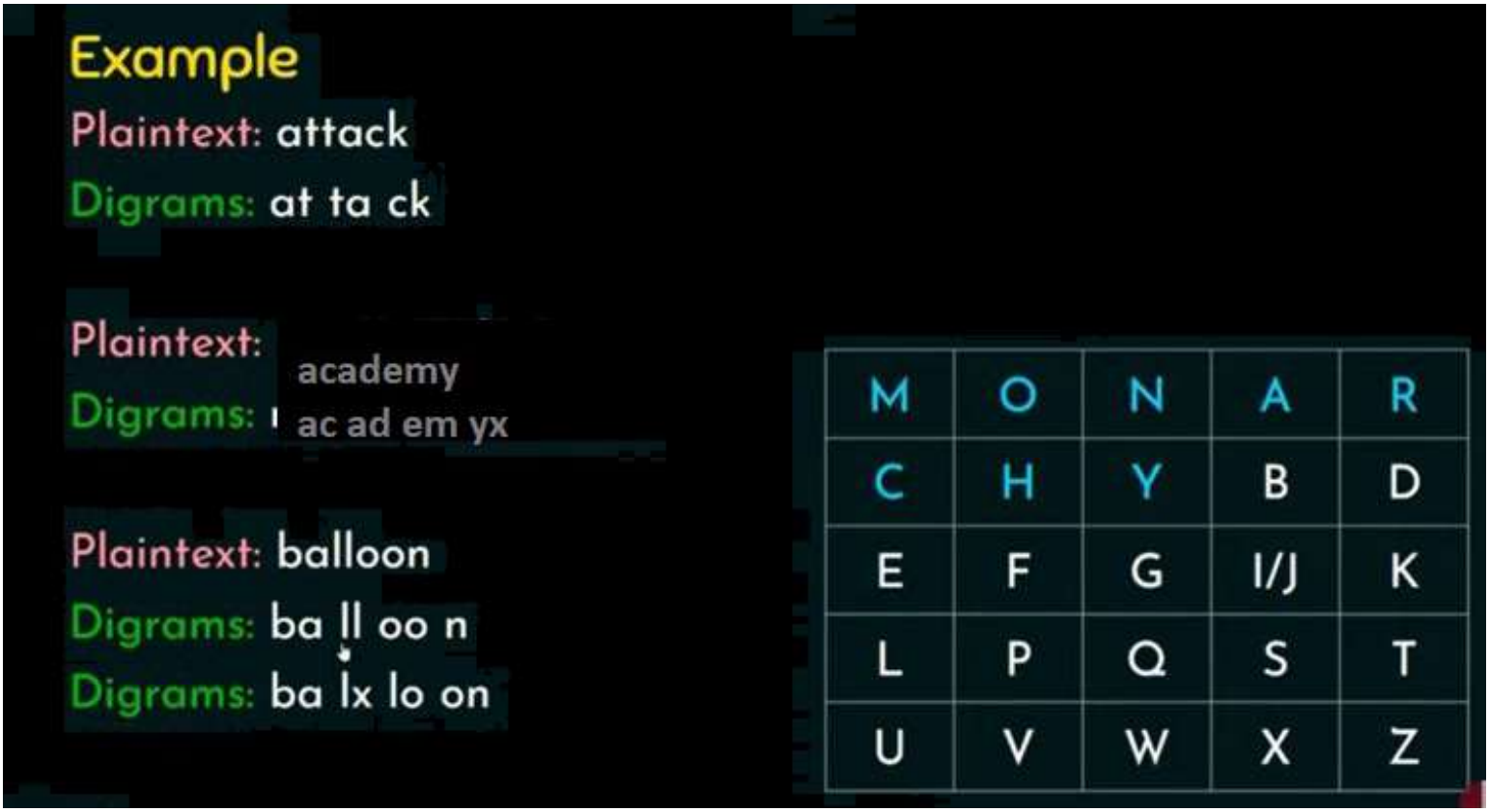
Playfair Cipher

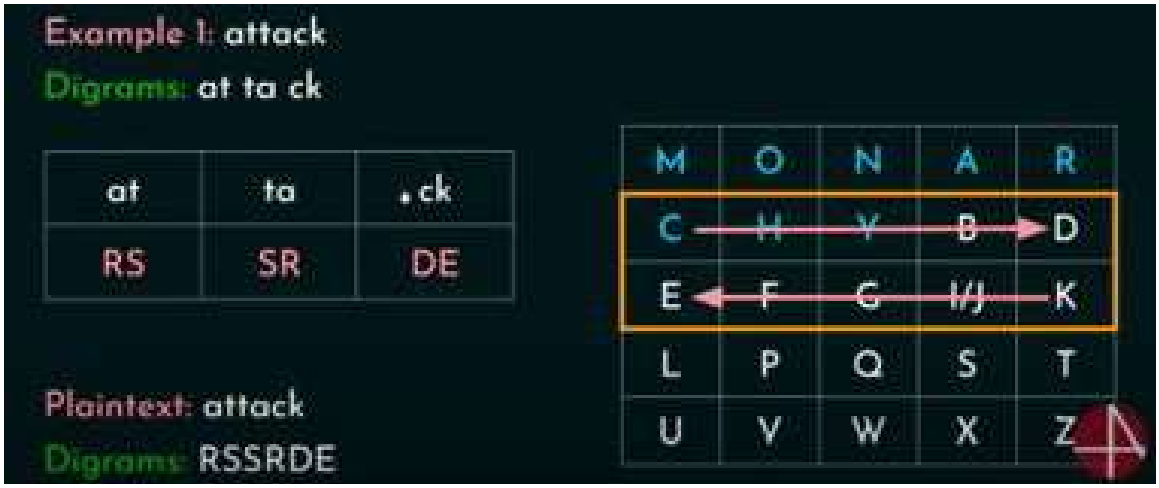
- Manual symmetric encryption technique
- Multiple-letter encryption cipher
- It treats digrams in the plaintext as single units and translates these units into ciphertext digrams.
- 5 X 5 matrix constructed using a keyword(Ex: Monarchy)

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

Rules for encryption using palyfair cipher

1. Digrams
2. Repeating/Missing Letters-Filler Letter
3. Same column- wrap around
4. Same row- wrap around
5. Rectangle-swap


Example
Plaintext: attack
Digrams: at ta ck
Plaintext: academy
Digrams: ac ad em yx
Plaintext: balloon
Digrams: ba ll oo n
Digrams: ba lx lo on
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


Example 1: attack
Digrams: at ta ck
at
ta
ck
RS
SR
DE
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
Plaintext: attack
Digrams: RSSRDE


Example 2: mosque
mo
sq
ue
ON
TS
ML
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
Plaintext: mosque
Digrams: ONTSML

PT: instruments

in:

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

st:

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

ru:

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

me:

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

nt:

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

sz:

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

Hill Cipher

- Multi letter cipher
- developed by Lester hill in 1929
- Encrypt a group of letters: digraph, trigraph or polygraph-depending on the key

Hill Cipher-Mathematical aspects

- linear algebra
- matrix arithmetic modulo 26
- Square matrix
- determinant
- multiplicative inverse

Hill Cipher-Algorithm

- C = E(K,P) = P * K mod26
- P = D(K,C) = C * K^{-1} mod26= P* K*K^{-1} mod26
  This can be expressed in terms of row vectors and matrices

$$(C_1\ C_2\ C_3) = (P_1\ P_2\ P_3) \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix} \bmod 26$$

Encryption

$$C_1 = (P_1K_{11} + P_2K_{21} + P_3K_{31}) \bmod 26$$
$$C_2 = (P_1K_{12} + P_2K_{22} + P_3K_{32}) \bmod 26$$
$$C_3 = (P_1K_{13} + P_2K_{23} + P_3K_{33}) \bmod 26$$

Question: Encrypt "pay more money" using Hill cipher with key

$$\begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix}$$

Solution:

p	a	y	m	o	r	e	m	o	n	e	y
15	0	24	12	14	17	4	12	14	13	4	24

Key = 3 x 3 matrix.

PT = pay mor emo ney

Encrypting: pay

$$(C_1\ C_2\ C_3) = (P_1\ P_2\ P_3) \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix} \bmod 26$$

$$(C_1\ C_2\ C_3) = (15\ 0\ 24) \begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix} \bmod 26$$

$$= (15\times17+0\times21+24\times2 \quad 15\times17+0\times18+24\times2 \quad 15\times5+0\times21+24\times19) \bmod 26$$

$$= (303\ 303\ 531) \bmod 26$$

$$= (17\ 17\ 11)$$

$$= (R\ R\ L)$$

Encrypting: mor

$$(C_1\ C_2\ C_3) = (P_1\ P_2\ P_3) \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix} \bmod 26$$

$$(C_1\ C_2\ C_3) = (12\ 14\ 17) \begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix} \bmod 26$$

$$= (12x17+14x21+17x2 \quad 12x17+14x18+17x2 \quad 12x5+14x21+17x19) \bmod 26$$

$$= (532\ 490\ 677) \bmod 26$$

$$= (12\ 22\ 1)$$

$$= (M\ W\ B)$$

Encrypting: emo

$$(C_1\ C_2\ C_3) = (P_1\ P_2\ P_3) \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix} \bmod 26$$

$$(C_1\ C_2\ C_3) = (4\ 12\ 14) \begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix} \bmod 26$$

$$= (4\times17+12\times21+14\times2 \quad 4\times17+12\times18+14\times2 \quad 4\times5+12\times21+14\times19) \bmod 26$$

$$= (348\ 312\ 538) \bmod 26$$

$$= (10\ 0\ 18)$$

$$= (K\ A\ S)$$

Encrypting: ney

$$(C_1\ C_2\ C_3) = (P_1\ P_2\ P_3) \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix} \bmod 26$$

$$(C_1\ C_2\ C_3) = (13\ 4\ 24) \begin{pmatrix} 17 & 17 & 5 \\ 21 & 18 & 21 \\ 2 & 2 & 19 \end{pmatrix} \bmod 26$$

$$= (13\text{x}17+4\text{x}21+24\text{x}2 \quad 13\text{x}17+4\text{x}18+24\text{x}2 \quad 13\text{x}5+4\text{x}21+24\text{x}19) \bmod 26$$

$$= (348\ 312\ 538) \bmod 26$$

$$= (15\ 3\ 7)$$

$$= (P\ D\ H)$$

PT	p	a	y	m	o	r	e	m	o	n	e	y
CT	R	R	L	M	W	B	K	A	S	P	D	H

Hill Cipher - Decryption

Polyalphabetic Cipher-Vigenere Cipher

- To improve on the mono alphabetic technique
- A set of related mono alphabetic substitution rules is used
- A key determines which particular rule is chosen for a given transformation
- Example:Vigenere Cipher
- 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
- To encrypt a message, a key is needed that is as long as the message.
- Usually, the key is a repeating keyword.

Vigenere Cipher

We can express the Vigenère cipher in the following manner. Assume a sequence of plaintext letters $P = p_0, p_1, p_2, \ldots, p_{n-1}$ and a key consisting of the sequence of letters $K = k_0, k_1, k_2, \ldots, k_{m-1}$, where typically $m < n$. The sequence of ciphertext letters $C = C_0, C_1, C_2, \ldots, C_{n-1}$ is calculated as follows:

$$\begin{aligned} C = C_0, C_1, C_2, \ldots, C_{n-1} &= \mathrm{E}(K, P) = \mathrm{E}[(k_0, k_1, k_2, \ldots, k_{m-1}), (p_0, p_1, p_2, \ldots, p_{n-1})] \\ &= (p_0 + k_0) \bmod 26, (p_1 + k_1) \bmod 26, \ldots, (p_{m-1} + k_{m-1}) \bmod 26, \\ &\quad (p_m + k_0) \bmod 26, (p_{m+1} + k_1) \bmod 26, \ldots, (p_{2m-1} + k_{m-1}) \bmod 26, \ldots \end{aligned}$$

Thus, the first letter of the key is added to the first letter of the plaintext, mod 26, the second letters are added, and so on through the first m letters of the plaintext. For the next m letters of the plaintext, the key letters are repeated. This process continues until all of the plaintext sequence is encrypted. A general equation of the encryption process is

$$C_i = (p_i + k_{i \bmod m}) \bmod 26 \qquad \textbf{(2.3)}$$

$$p_i = (C_i - k_{i \bmod m}) \bmod 26$$

- KEY : deceptive
- Plain Text: "we are discovered save yourself"

```
key:            deceptivedeceptivedeceptive
plaintext:      wearediscoveredsaveyourself
ciphertext:     ZICVTWQNGRZGVTWAVZHCQYGLMGJ
```

Expressed numerically, we have the following result.

key	3	4	2	4	15	19	8	21	4	3	4	2	4	15
plaintext	22	4	0	17	4	3	8	18	2	14	21	4	17	4
ciphertext	25	8	2	21	19	22	16	13	6	17	25	6	21	19

key	19	8	21	4	3	4	2	4	15	19	8	21	4
plaintext	3	18	0	21	4	24	14	20	17	18	4	11	5
ciphertext	22	0	21	25	7	2	16	24	6	11	12	6	9

Vigenere Cipher-Cryptanalysis

- As cryptography is the science and art of creating secret codes, cryptanalysis is the science and art of breaking those codes.
- Determining the length of the keyword
- Key and the Plaintext share the same frequency distribution of letters, a statistical technique can be applied
- **Autokey System:** The periodic nature of the keyword can be eliminated by using a nonrepeating keyword that is as long as the message itself.
- Vigenère proposed what is referred to as an autokey system, in which a keyword is concatenated with the plaintext itself to provide a running key.

```
key:          deceptivewearediscoveredsav
plaintext:    wearediscoveredsaveyourself
ciphertext:   ZICVTWQNGKZEIIGASXSTSLVVWLA
```

Polyalphabetic Cipher-Vernam Cipher

- Need of ultimate defense against such a cryptanalysis
- Introduced by Gilbert Vernam in 1918.
- This system works on binary data (bits) rather than letters
- Length of Keyword=Length of Plaintext
- no statistical relationship to it.
- This system can be expressed as follows:

$$c_i = p_i \oplus k_i$$

where

p_i = ith binary digit of plaintext
k_i = ith binary digit of key
c_i = ith binary digit of ciphertext
$\oplus$ = exclusive-or (XOR) operation

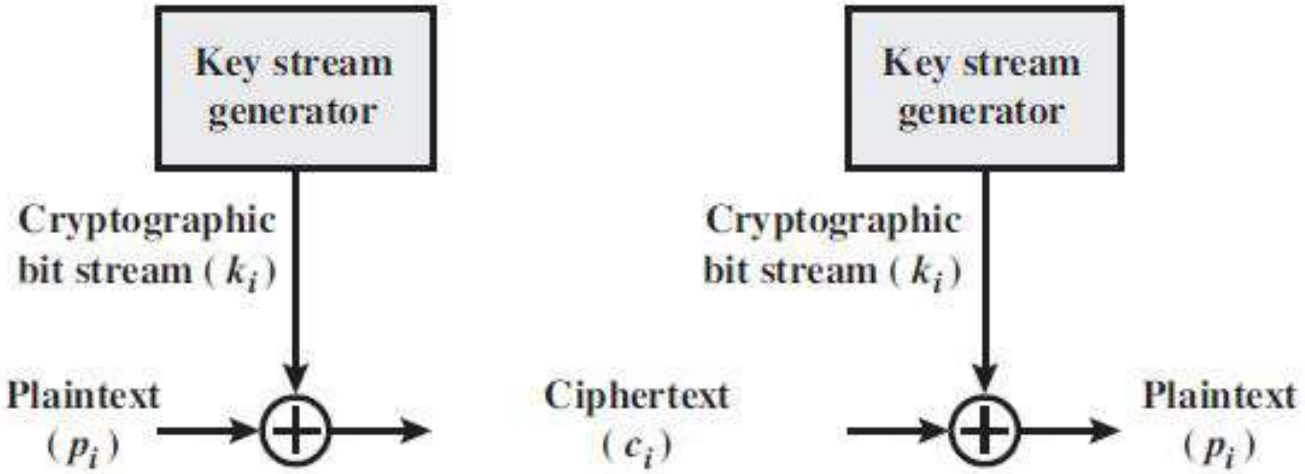


Figure 2.7 Vernam Cipher

Encryption Algorithm-Steps

1. Assign a number to each character of the plain text and the key according to alphabetical order.
2. Bitwise XOR both the number (Corresponding plain-text character number and Key character number).
3. Subtract the number from 26 if the resulting number is greater than or equal to 26, if it isn't then leave it.

Example

Plain-Text: O A K

Key: S O N

O ==> 14 = 0 1 1 1 0

S ==> 18 = 1 0 0 1 0

Bitwise XOR Result: 1 1 1 0 0 = 28

Since the resulting number is greater than 26, subtract 26 from it. Then convert the Cipher-Text character number to the Cipher-Text character.

28 - 26 = 2 ==> C

CIPHER-TEXT: C

Similarly, do the same for the other corresponding characters,

```
PT: O  A  K
NO: 14 00 10
KEY: S  O  N
NO:  18 14 13
```

New Cipher-Text is after getting the corresponding character from the resulting number.

```
CT-NO: 02 14 07
CT:    C  O  H
```

Example 2

Plain-Text: RAMSWARUPK
Key: RANCHOBABA

Vernam Cipher-Cryptanalysis

- Construction of the key
- Vernam proposed the use of a running loop of tape that eventually repeated the key
- The system worked with a very long but repeating keyword.
- It can be broken with sufficient ciphertext, the use of known or probable plaintext sequences, or both.

One-Time Pad

- Improvement to the vernam Cipher
- Yield ultimate aim in security
- Random key that is as long as the message
- The key need not be repeated
- In addition the key is to be 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
- Such a scheme, known as a one-time pad, is unbreakable
- It produces random output
- 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
- The security of the one time pad is entirely due to the randomness of the key

Example

ANKYODKYUREPFJBYOJDSPLREYIUNOFDOIUERFPLUYTS

We now show two different decryptions using two different keys:

```
ciphertext: ANKYODKYUREPFJBYOJDSPLREYIUNOFDOIUERFPLUYTS
key:        pxlmvmsydofuyrvzwc tnlebnecvgdupahfzzlmnyih
plaintext:  mr mustard with the candlestick in the hall
```

```
ciphertext: ANKYODKYUREPFJBYOJDSPLREYIUNOFDOIUERFPLUYTS
key:        mfugpmiydgaxgoufhkllmhsqdqogtewbqfgyovuhwt
plaintext:  miss scarlet with the knife in the library
```

Two fundamental difficulties

- Making large quantities of random keys
- Key distribution and protection
- Because of these difficulties, the one-time pad is of limited utility and is useful primarily for low-bandwidth channels requiring very high security
- The one-time pad is the only cryptosystem that exhibits what is referred to as perfect secrecy

Transposition Cipher

- some sort of permutation on the plaintext letters
- 2 methods
  1. Rail fence method
  2. Row Column Transposition

Rail Fence Technique

- The simplest method
- The plaintext is written down as a sequence of diagonals and then read off as a sequence of rows.
- For example, to encipher the message "**meet me after the toga party**" with a rail fence of **depth 2**

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

e t e f e t e o a a t

The encrypted message is

MEMATRHTGPRYETEFETEOAAT

Row Column Transposition

- More complex
- Rectangle
- Write: Row by row
- Read: Column by column
- Key: Order of the column
- PT: attack postponed until two am

```
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
```

- To encrypt, start with the column that is labeled 1, in this case column 3.
- Write down all the letters in that column. Proceed to column 4, which is labeled 2, then column 2, then column 1, then columns 5, 6, and 7.