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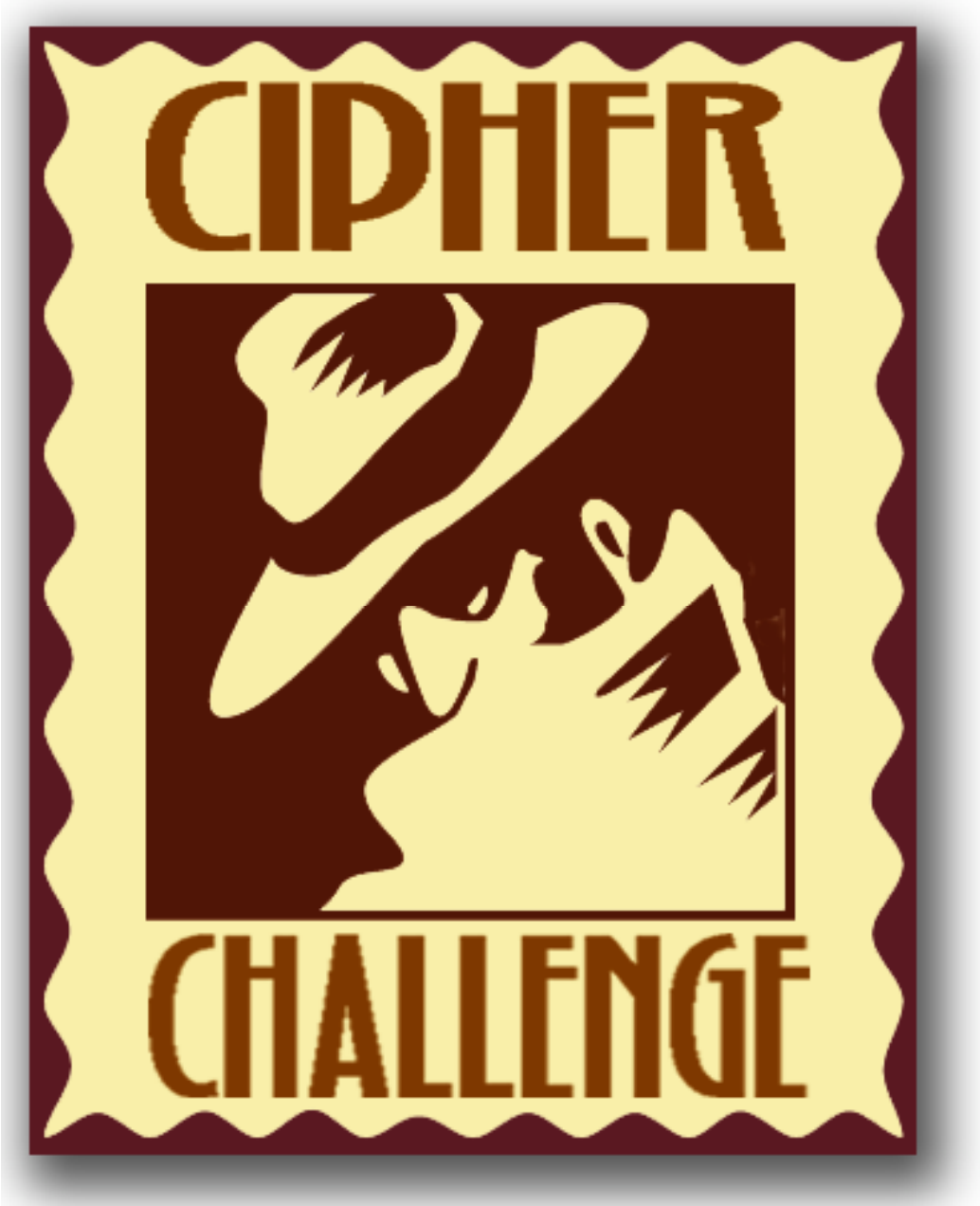
National Cipher Challenge



Teachers' notes to accompany the lesson packs

On substitution ciphers

These notes form a brief introduction to substitution ciphers, to accompany the lesson plans provided with the University of Southampton National Cipher Challenge, 2003. We would like to thank Hugh Evans of Sholing Technology College for his assistance in the design of these teaching materials.

Caesar shift ciphers

a D

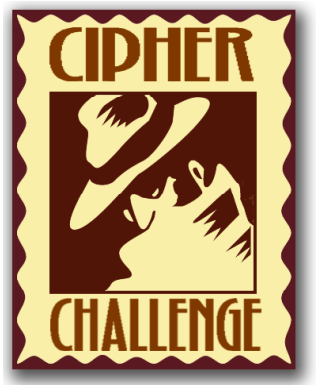
b E

WKH HDVLHVW PHWKRG RI HQFLSKHULQJ D WHAW PHVVDJH LV WR UHSODFH HDFK FKDUDFWHU EB DQRWKHU XVLQJ D ILAHG UXOH, VR IRU HADPSOH HYHUB OHWWHU D PDB EH UHSODFHG EB G, DQG HYHUB OHWWHU E EB WKH OHWWHU H DQG VR RQ.

e

he e H

the WKH


CIPHER
CHALLENGE

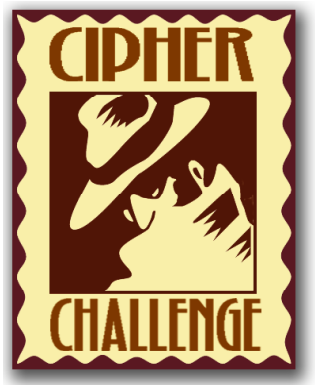
Keyword substitution ciphers

abcdefghijklmnopqrstuvwxyz
THESIMPONQRUVWXYZABCDFGJKL

VEP HYXHLVHTP MO AWFJYFLT H RFNEPS HJNEHAPV FL VEFU ZHC FU VEHV FV FU PHUC VM KPKMSFUP VEP IPCZMSY MS IPCNESHUP, HLY EPLRP VEP RFNEPS HJNEHAPV. VEFU FU FKNMSVHLV, APRHWUP FO VEP UPLYPS EHU VM IPPN VEP RFNEPS HJNEHAPV ML H NFPRP MO NHNPS, VEP PLPKC RHL RHNVWSP VEP NHNPS, YFURMXPS VEP IPC, HLY SPHY HLC RMKKWLFRHVFMLU VEHV EHXP APPL PLRSCNVPY ZFVE FV. EMZPXPS FO VEP IPC RHL AP RMKKFVVPY VM KPKMSC FV FU JPUU JFIPJC VM OHJJ FLVM PLPKC EHLYU.

the e
P
e.g., and but P
e
P e
V t E h

the HYXHLtHTe MO AWFJYFLT H RFNheS HJNhHAet FL thFU ZHC FU thHt Ft FU eHUC tM KeKMSFUe the IeCZMSY MS IeCNhSHUe, HLY heLRe the RFNheS HJNhHAet. thFU FU FKNMStHLt, AeRHWUe FO the UeLYeS hHU tM IeeN the RFNheS HJNhHAet ML H NFeRe MO NHNeS, the eLeKC RHL RHNtWSe the NHNeS, YFURMXeS the IeC, HLY SeHY HLC RMKKWLFRHtFMLU thHt hHXe AeeL eLRSCNteY ZFth Ft. hMZeXeS FO the IeC RHL Ae RMKKFtteY tM KeKMSC Ft FU JeUU JFIeJC tM OHJJ FLtM eLeKC hHLYU.



H

thHt H

a

the aYXaLtaTe MO AWFJYFLT a RFNheS aJNhaAet FL thFU ZaC FU that Ft FU eaUC tM KeKMSFUe the IeCZMSY MS IeCNhSaUe, aLY heLRe the RFNheS aJNhaAet. thFU FU FKNMStaLt, AeRaWUe FO the UeLYeS haU tM IeeN the RFNheS aJNhaAet ML a NFeRe MO NaNeS, the eLeKC RaL RaNtWSe the NaNeS, YFURMXeS the IeC, aLY SeaY aLC RMKKWLFRatFMLU that haXe AeeL eLRSCNteY ZFth Ft. hMZeXeS FO the IeC RaL Ae RMKKFtteY tM KeKMSC Ft FU JeUU JFIeJC tM OaJJ FLtM eLeKC haLYU.

the aYXaLtaTe MO AWiJYiLT a RiNheS aJNhaAet iL this ZaC is that it is easC tM KeKMSise the IeCZMSY MS IeCNhSase, aLY heLRe the RiNheS aJNhaAet. this is iKNMStaLt, AeRaWse iO the seLYeS has tM IeeN the RiNheS aJNhaAet ML a NieRe MO NaNeS, the eLeKC RaL RaNtWSe teh NaNeS, YisRMXeS the IeC, aLY SeaY aLC RMKKWLiRatiMLs that haXe AeeL eLRSCNteY Zith it. hMZeXeS iO the IeC RaL Ae RMKKitteY tM KeKMSC it is Jess JiIeJC tM OaJJ iLtM eLeKC haLYs.

haXe have easC easy

The Code Book

“The advantage of building a cipher alphabet in this way is that it is easy to memorise the keyword or keyphrase, and hence the cipher alphabet. This is important, because if the sender has to keep the cipher alphabet on a piece of paper, the enemy can capture the paper, discover the key, and read any communications that have been encrypted with it. However if the key can be committed to memory it is less likely to fall into enemy hands."

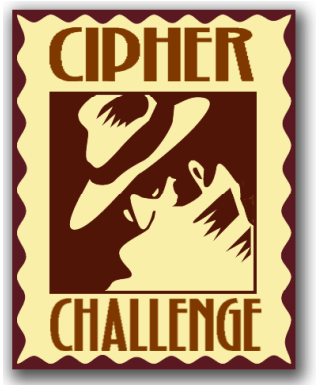
Frequency analysis

a	b	c	d	e	f	g	h	i	j	k	l	m
7	0	12	0	26	27	0	32	6	9	11	20	18
n	o	p	q	r	s	t	u	v	w	x	y	z
16	5	55	0	14	17	2	17	35	4	4	11	4

a	b	c	d	e	f	g	h	i	j	k	l	m
8.2	1.5	2.8	4.3	12.7	2.2	2.0	6.1	7.0	0.2	0.8	4.0	2.4
n	o	p	q	r	s	t	u	v	w	x	y	z
6.7		1.9	0.1	6.0	6.3	9.1	2.8	1.0	2.4	0.2	2.0	0.1

Disguising the word structure

```
VEPHY XHLVH TPMOA WFJYF LTHRF NEPSH JNEHA PVFLV EFUZH
CFUVE HVFVF UPHUC VMKPK MSFUP VEPIP CZMSY MSIPC NESHU
PHLYE PLRPV EPRFN EPSHJ NEHAP VVEFU FUFKN MSVHL VAPRH
WUPFO VEPUP LYPSE HUVMI PPNVE PRFNE PSHJN EHAPV MLHNF
PRPMO NHNPS VEPPL PKCRH LRHNV WSPVE PNHNP SYFUR MXPSV
EPIPC HLYSP HYHLC RMKKW LFRHV FMLUV EHVEH XPAPP LPLRS
CNVPY ZFVEF VEMZP XPSFO VEPIP CRHLA PRMKK FVVPY VMKPK
MSCFV FUJPU UJFIP JCVMO HJJFL VMPLP KCEHL YU
```



something

Enigma

Affine shift ciphers

a	b	c	d	e	f	g	h	i	j	k	l	m
1	2	3	4	5	6	7	8	9	10	11	12	13
n	o	p	q	r	s	t	u	v	w	x	y	z
14	15	16	17	18	19	20	21	22	23	24	25	26

a	b	c	d	e	f	g	h	i	j	k	l	m
4	5	6	7	8	9	10	11	12	13	14	15	16
n	o	p	q	r	s	t	u	v	w	x	y	z
17	18	19	20	21	22	23	24	25	26	1	2	3

a	b	c	d	e	f	g	h	i	j	k	l	m
d	e	f	g	h	i	j	k	l	m	n	o	p
n	o	p	q	r	s	t	u	v	w	x	y	z
q	r	s	t	u	v	w	x	y	z	a	b	c

n $x \rightarrow x+n$

x n

i.e. *x* *n*

n

The affine shift *x* → 3*x*+5

x *x*+ *x*+

→ →

x+

a	b	c	d	e	f	g	h	i	j	k	l	m
8	11	14	17	20	23	26	3	6	9	12	15	18
n	o	p	q	r	s	t	u	v	w	x	y	z
21	24	1	4	7	10	13	16	19	22	25	2	5

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

x → *ax*+*b*

a

x → *x*+ *x* → *x*

e

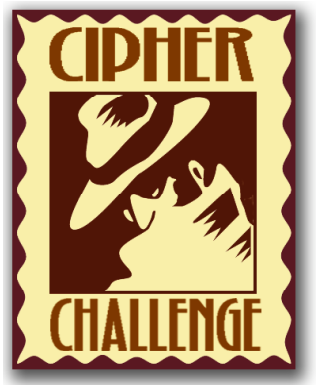
ax+*b*

a *b*

x → *ax*+*b*

ax+*b* *x*

a *a*



$x \rightarrow 2x$ m z

Z

Z m

z

$x \rightarrow ax+b$

a

a

b

Polyalphabetic ciphers

e X G

X G

etc..

a z

The Code Book

Cryptography Lesson Plan 1

Class: Cracking the Caesear shift ciphers.
Resources:

- **Leaflet "On substitution ciphers".**
- **Two handouts each with a plaintext and a cipher table**
- **Teachers' solutions for the handouts.**
- **One OHP slide with cipher text to crack, and partial decrypt and solution.**

Starter: (10 minutes approximately) Uses handouts for Groups A and B
Encryption exercise – split the class into groups A and B. Give each group the enclosed text to encipher using the given code. Encourage accuracy AND secrecy! Answers enclosed with handouts.

Main activity: (40 minutes approx) Uses OHP

- *Introduce the idea of a substitution cipher in general and the Caesar shift in particular.*
- *Suggest trial and error as a deciphering technique.*
- *Work through a very simple Caesar shift (by 3).*
- *Split the class again, swap over the ciphertexts from the starter exercise and get them to tackle them.*

Plenary (approx 10 minutes)

Discuss how to make the code harder to crack using a rule that is harder to determine, but remark on the need for an easy to remember rule (stressed agents must remember it and can't write it down!) Mention "keyword" substitution.

Handout for lesson 1.

GROUP A

Code: Caesar shift by 2

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
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

Plaintext

There were plenty of schools in the world, but they were all run either by the various churches or the Guilds. Miss Butts objected to churches on logical grounds and deplored the fact that the only Guilds that considered girls worth educating were the Thieves and the Seamstresses. It was a big and dangerous world out there and a girl could do worse than face it with a sound knowledge of geometry and astronomy under her bodice.
From "Soul Music" by Terry Pratchett.

Handout for lesson 1.

GROUP B

Code: Caesar shift by 4

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
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

Plaintext

The four houses are called Gryffindor, Hufflepuff, Ravenclaw and Slytherin. Each house has its own noble history and each has produced outstanding witches and wizards. While you are at Hogwarts, your triumphs will earn your house points, while any rule-breaking will lose house points. At the end of the year the house with the most points is awarded the House Cup, a great honour. I hope each of you will be a credit to whichever house becomes yours.
From "Harry Potter and the Philosopher's Stone" by J.K. Rowling.

Teachers' solutions to encryption challenge

Ciphertext A

```
VJGTG YGTG RNGPVA QH UEJQQNU KP VJG YQTNF, DWV VJGA YGTG
CNN TWP GKVJGT DA VJG XCTKQWU EJWTEJGU QT VJG IWKNFU.
OKUU DWVVU QDLGEVGF VQ EJWTEJGU QP NQIKECN ITQWPFU CPF
FGRNQTGF VJG HCEV VJCV VJG QPNA IWKNFU VJCV EQPUKFGTGF
IKTNU YQTVJ GFWECVKPI YGTG VJG VJKGXGU CPF VJG
UGCOUVTGUUGU. KV YCU C DKI CPF FCPIGTQWU YQTNF QWV VJGTG
CPF C IKTN EQWNF FQ YQTUG VJCP HCEG KV YKVJ C UQWPF
```

OHP Slide for lesson 1

Ciphertext

```
WKH HDVLHVW PHWKRG RI
HQFLSKHULQJ D WHAW PHVVDJH
LV WR UHSODFH HDFK
FKDUDFWHU EB DQRWKHU XVLQJ
D ILAHG UXOH, VR IRU HADPSOH HYHUB
OHWWHU D PDB EH UHSODFHG EB G, DQG
HYHUB OHWWHU E EB WKH OHWWHU H DQG VR
RQ.
```

Partial decrypt: Guess that the first word is "`the`" so that `t` is enciphered as `W`, `h` as `K` and `e` as `H`. This suggests a shift by 3:

```
the eDVLeVt PethRG RI eQFLSheULQJ D
teAt PeVVDJe LV tR UeSODFe eDFh
FhDUDFteU EB DQRtheU XVLQJ D ILAeG
UXOe, VR IRU eADPSOe eYeUB OetteU D
PDB Ee UeSODFeG EB G, DQG eYeUB OetteU
E EB the OetteU e DQG VR RQ.
```

The word `teAt` could be `tent`, `test` or `text`, with `text` fitting with the shift by 3; the word `OetteU` which occurs twice, would decipher to "letter" confirming our guess.

Code: Caesar shift by 3

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

Plaintext

The easiest method of enciphering a text message is to replace each character by another using a fixed rule, so for example every letter a may be replaced by d, and every letter b by the letter e and so on.

Cryptography Lesson Plan 2

Class: Cracking keyword substitution ciphers – emphasises letter frequency analysis and team work.

Resources:

- **Leaflet "On substitution ciphers".**
- **OHP 1 containing ciphertext**
- **OHP 2 Containing expected frequency table and incomplete actual frequencies.**
- **Handout summarising details of deciphering technique.**
- **OHP 3 With further thoughts on disguising the text.**

Starter: (10 minutes approximately) (Uses OHP 1)
Split the class into teams and get them to count the letter frequencies in the ciphertext. Emphasise the need for speed and accuracy. Maybe set the scene as a race against time.

Main activity: (30 minutes approx) (Uses OHP 1 and OHP 2 and handout)

- *Introduce the idea of a keyword cipher to make encryption more secure and more memorable (see "On substitution ciphers").*
- *Discuss the hunt for common words and letters and introduce frequency analysis – show a table of common frequencies and check it against the examples in lesson 1.*
- *Discuss the speed improvements given by parallel processing of the text. Split into 26 teams to do a frequency analysis of the given ciphertext on OHP 1. {It may be worth remarking that standard computer attacks on ciphers use this idea of parallel processing to speed up the attack.)*
- *Whole class session to construct frequency table, compare with expected frequencies (computed from percentages) and identify the letters "e" and "t".*

Plenary (20 minutes approx) (Uses OHP 2 and, time permitting OHP 3)

Draw together the intelligence gained by the groups and crack the cipher together. (You may wish to give out the handout summarising the technique after completing the exercise.)

If time permits (OHP 3):

- *Discuss how to make the code harder to crack by disguising the letter groups.*
- *Remark that the frequency table can mislead for non-standard or foreign language texts! Examine the extract from the book "A Void" by Georges Perec.*

OHP Slide 1 for lesson 2

Ciphertext

VEP HYXHLVHTP MO AWFJYFLT H RFNEPS HJNEHAPV FL VEFU ZHC FU VEHV FV FU PHUC VM KPKMSFUP VEP IPCZMSY MS IPCNESHUP, HLY EPLRP VEP RFNEPS HJNEHAPV. VEFU FU FKNMSVHLV, APRHWUP FO VEP UPLYPS EHU VM IPPN VEP RFNEPS HJNEHAPV ML H NFPRP MO NHNPS, VEP PLPKC RHL RHNVWSP VEP NHNPS, YFURMXPS VEP IPC, HLY SPHY HLC RMKKWLFRHVFMLU VEHV EHXP APPL PLRSCNVPY ZFVE FV. EMZPXPS FO VEP IPC RHL AP RMKKFVVPY VM KPKMSC FV FU JPUU JFIPJC VM OHJJ FLVM PLPKC EHLYU.

OHP Slide 2 for lesson 2

Occurrences table

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

Expected Frequency table

a	b	c	d	e	f	g	h	i	j	k	l	m
8.2	1.5	2.8	4.3	12.7	2.2	2.0	6.1	7.0	0.2	0.8	4.0	2.4
n	o	p	q	r	s	t	u	v	w	x	y	z
6.7	7.5	1.9	0.1	6.0	6.3	9.1	2.8	1.0	2.4	0.2	2.0	0.1

This table was taken from "The Code Book" by Simon Singh, and gives expected frequencies as a percentage. To accurately compare it to the actual frequencies above you should compute the actual frequencies as percentages.

Actual Frequencies as percentages

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

Handout for lesson 2

STAGE 1 – P is the commonest letter in the ciphertext so could stand for e - maybe the first word is the:

```
the HYXHLtHTe MO AWFJYFLT H RFNheS
HJNhHAet FL thFU ZHC FU thHt Ft FU eHUC
tM KeKMSFUe the IeCZMSY MS IeCNhSHUe,
HLY heLRe the RFNheS HJNhHAet. thFU FU
FKNMStHLt, AeRHWUe FO the UeLYeS hHU tM
IeeN the RFNheS HJNhHAet ML H NFeRe MO
NHNeS, the eLeKC RHL RHNtWSe the NHNeS, YFURMXeS the IeC,
HLY SeHY HLC RMKKWLFRHtFMLU thHt hHXe AeeL eLRSCNteY ZFth
Ft. hMZeXeS FO the IeC RHL Ae RMKKFtteY tM KeKMSC Ft FU
JeUU JFIeJC tM OHJJ FLtM eLeKC hHLYU.
```

STAGE 2 We see the single letter word H, and the four letter word thHt in the first line - guess that H encodes the letter a.

```
the aYXaLtaTe MO AWFJYFLT a RFNheS aJNhaAet FL thFU ZaC
FU that Ft FU eaUC tM KeKMSFUe the IeCZMSY MS IeCNhSaUe,
aLY heLRe the RFNheS aJNhaAet. thFU FU FKNMStaLt, AeRaWUe
FO the UeLYeS haU tM IeeN the RFNheS aJNhaAet ML a NFeRe
MO NaNeS, the eLeKC RaL RaNtWSe the NaNeS, YFURMXeS the
IeC, aLY SeaY aLC RMKKWLFRatFMLU that haXe AeeL eLRSCNteY
ZFth Ft. hMZeXeS FO the IeC RaL Ae RMKKFtteY tM KeKMSC Ft
FU JeUU JFIeJC tM OaJJ FLtM eLeKC haLYU.
```

STAGE 3 The two 2 letter words Ft FU are probably it is meaning that F encodes i and U encodes s:

```
the aYXaLtaTe MO AWiJYiLT a RiNheS aJNhaAet iL this ZaC
is that it is easC tM KeKMSise the IeCZMSY MS IeCNhSase,
aLY heLRe the RiNheS aJNhaAet. this is iKNMStaLt, AeRaWse
iO the seLYeS has tM IeeN the RiNheS aJNhaAet ML a NieRe
MO NaNeS, the eLeKC RaL RaNtWSe teh NaNeS, YisRMXeS the
IeC, aLY SeaY aLC RMKKWLiRatiMLs that haXe AeeL eLRSCNteY
Zith it. hMZeXeS iO the IeC RaL Ae RMKKitteY tM KeKMSC it
is Jess JiIeJC tM OaJJ iLtM eLeKC haLYs.
```

STAGE 4: haXe = have, easC = easy and so on - we get the following extract from Simon Singh's excellent history of codes and ciphers, *The Code Book*:

"The advantage of building a cipher alphabet in this way is that it is easy to memorise the keyword or keyphrase, and hence the cipher alphabet. This is important, because if the sender has to keep the cipher alphabet on a piece of paper, the enemy can capture the paper, discover the key, and read any communications that have been encrypted with it. However if the key can be committed to memory it is less likely to fall into enemy hands."

OHP Slide 3 for lesson 2

Obscuring a substitution cipher

1. We can disguise the word structure by regrouping the letters into blocks:

```
VEPHY XHLVH TPMOA WFJYF LTHRF NEPSH JNEHA PVFLV
EFUZH CFUVE HVFVF UPHUC VMKPK MSFUP VEPIP CZMSY
MSIPC NESHU PHLYE PLRPV EPRFN EPSHJ NEHAP VVEFU
FUFKN MSVHL VAPRH WUPFO VEPUP LYPSE HUVMI PPNVE
PRFNE PSHJN EHAPV MLHNF PRPMO NHNPS VEPPL PKCRH
LRHNV WSPVE PNHNP SYFUR MXPSV EPIPC HLYSP HYHLC
RMKKW LFRHV FMLUV EHVEH XPAPP LPLRS CNVPY ZFVEF
VEMZP XPSFO VEPIP CRHLA PRMKK FVVPY VMKPK MSCFV
FUJPU UJFIP JCVMO HJJFL VMPLP KCEHL
YU
```

2. We can distort the frequency table – this text was adapted for last years cipher challenge!

Augustus, who has had a bad night, sits up blinking and purblind. Oh what was that word (is his thought) that ran through my brain all night, that idiotic word that, hard as I'd try to pin it down, was always just an inch or two out of my grasp - fowl or foul or Vow or Voyal? - a word which, by association, brought into play an incongruous mass and magma of nouns, idioms, slogans and sayings, a confusing, amorphous outpouring which I sought in vain to control or turn off but which wound around my mind a whirlwind of a cord, a whiplash of a cord, a cord that would split again and again, would knit again and again, of words without communication or any possibility of combination, words without pronunciation, signification or transcription but out of which, notwithstanding, was brought forth a flux, a continuous, compact and lucid flow: an intuition, a vacillating frisson of illumination as if caught in a flash of lightning or in a mist abruptly rising to unshroud an obvious sign - but a sign, alas, that would last an instant only to vanish for good.

From "A Void" by Gilbert Adair. The letter "e" does not appear even once in the book!

Cryptography Lesson Plan 3

Class: Affine shift ciphers – emphasises clock arithmetic and gives more practice at frequency analysis.

Resources:

- **Leaflet "On substitution ciphers".**
- **OHP 1, giving partial encryption table for the 3x+5 affine shift cipher together with teachers' solution.**
- **OHP 2-4, with cipher text to crack, method and solution.**

Starter: (10 minutes approximately) Uses handout
Complete the encryption table on the OHP (the affine shift cipher $x \rightarrow 3x+5$ is discussed in the teachers' notes).
Encourage them to try to spot the pattern and guess the rule which should be concealed.

Main activity: (40 minutes approx) Uses OHP

- *Introduce the class of affine shift ciphers mentioning "clock arithmetic" mod 26*
- *Show them that the cipher table arises from the affine shift $x \rightarrow 3x + 5$.*
- *Discuss the fact that you only need to know the value of two letters to deduce the affine shift (solving two simultaneous equations mod 26).*
- *Use frequency analysis and modular arithmetic to decipher an affine shifted text together or in groups.*

Plenary (approx 10 minutes)

Discuss generalisations to modular arithmetic mod n.

OHP slide 1 for lesson 3.

Spot the pattern?

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
H	K	N					C																		

x→ 3x + 5

1	2	3	4	5	6	7	8	9	10	11	12	13
8	11	14	17	20	23	26	3	16	9	12	15	18
14	15	16	17	18	19	20	21	22	23	24	25	26
21	24	1	4	7	10	13	16	19	22	25	2	5

Encryption table

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

OHP Slide 2 for lesson 3

Ciphertext

```
LMYFU BKUUS DDYFA XWCLA OLPSF AOLMJ FASDS
NSFGJ FAOEL SOMYT DJLAX EMHJM BFMIB JUMIS
HFSUL AXUBA FKJAM XLSKF FKXWS DJLSO FGBJM
WFKIU OLFMX MTMWA OKTTG JLSXL SKFFK XWSDJ
LSIZG TSXWJ LJLSX LSUMF JSDJL SIZGH FSQYS
XOGLS DMMDT SDMXJ LSBAT SMHBK BSFLS BFMCT
SDKFM YXDJL SLYJM ZTANA MYUXM CJMCL MCKUT
MMEAX WKJLA IKXDC LMCKU XJJLA UCKUC LKJAJ
LKDZS SXTAE SHMFJ SXAXJ SFIAX KZTSI MXJLU
TKUJG SKFXM CMXDS FLSLK DWMXS IKDJL SOLMF
YUTAX SMHIS KXAXW TSUUT SJJSF UDKXO SDZSH
MFSLA USGSU ZYJJL SGCSF SXMJI SKXAX WTSUU
JLSGC SFSTM KDSDC AJLJL SIMUJ NAJKT ISKXA
XWAIK WAXKZ TSAHM XTGLS OMYTD HAXDA JZYJC
LSFSC KUJLS BKJJS FXCLS FSCKU JLSBK JJSFX
CLSFS CKUJL SBKJJ SFXHF MISXA WIKZG FMZSF
JLKFF AU
```

Occurences table:

A	B	C	D	E	F	G	H	I	J	K	L	M
34	12	19	23	4	41	12	10	16	50	38	46	42
N	O	P	Q	R	S	T	U	V	W	X	Y	Z
3	11	1	1	0	78	22	28	0	13	41	11	11

OHP Slide 3 for lesson 3

Use frequency analysis to guess that S enciphers for e, and J for t.

This tells us that for an affine shift cipher

$x \rightarrow ax + b$

$a.5 + b = 19$ (e → S)
$a.20 + b = 10$ (t → J)

Solving mod 26 we see that $15.a = -9$ mod 26. Now 7.15 is congruent to 1 mod 26 since 7.15 = 105 = 104 +1= 4.26 +1. It follows that $7.15.a = 7.-9$, or a is congruent to -63.

Now -63 = -52 - 11, so a is congruent to -11, or equivalently to 15 mod 26. Hence $a = 15$. Now from $a.5 + b = 19$ we get $75 + b$ is congruent to 19, or b is congruent to –56 mod 26.

Since -56 = -2.26 - 4, b is congruent to -4 mod 26 so $b = 22$.

To check this $20.a + b = 300 + 22 = 322 = 12.26 + 10$, so $a.20 + b = 10$ as required. So the affine shift is $x \rightarrow 15x+22$ and the decrypt is given by the inverse function $y \rightarrow 7(y-22)$

[It might look strange but "dividing by 15" is the same as multiplying by 7 in mod 26 arithmetic.]

Equivalently the decryption is achieved by the affine shift $y \rightarrow 7y+2$.

Encryption table:

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

OHP Slide 4 for lesson 3

Decrypt

```
hours passe dduri ngwhi chjer ichot riede
veryt rickh ecoul dthin kofto promp tsome
fresh inspi ratio nhear range dthec rypto
grams chron ologi cally thenh earra ngedt
hemby lengt hthen hesor tedth embyf reque
ncyhe doodl edont hepil eofpa perhe prowl
edaro undth ehuto blivi ousno wtowh owasl
ookin gathi mandw howas ntthi swasw hatit
hadbe enlik efort enint ermin ablem onths
lasty earno wonde rheha dgone madth echor
uslin eofme aning lessl etter sdanc edbef
orehi seyes butth eywer enotm eanin gless
theyw erelo adedw ithth emost vital meani
ngima ginab leifo nlyhe could findi tbutw
herew asthe patte rnwhe rewas thepa ttern
where wasth epatt ernfr omeni gmaby rober
tharr is
```

Cipher Wheel