

Cryptography: Vigenère and Kasiski

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- ▶ The Vigenère cipher was developed and was thought to tackle these problems.

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- ▶ The solution: don't rely on just one substitution alphabet.
- ▶ Instead of a *monoalphabetic* cipher, a **polyalphabetic** cipher was designed.
- ▶ The use of polyalphabetic ciphers is thought to have originated with Leon Battista Alberti in 1467.



Vigenère Cipher



- ▶ Attributed to Blaise de Vigenère, it was known as 'le chiffre indéchiffrable': the unbreakable cipher. As it turns out, de Vigenère's original cipher was actually more secure than that which came to bear his name.
- ▶ Used for many centuries, this was the state of the art, and truly thought to be unbreakable.

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- ▶ The alphabets form a square: the Vigenère square, or *tabula recta*.

	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

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- ▶ The keyword is written repeatedly along the message. We look up the row of the key and match it to the column of the plaintext: row C and column i gives ciphertext K.

key	C	O	D	E	S	C	O	D	E	S	C	O	D	E	S	C	O	D	E	S
plain	i	n	v	a	d	e	a	t	d	a	w	n	o	n	f	r	i	d	a	y
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- ▶ Can also be thought of in terms of modular arithmetic:

keyword	2	14	3	4	18	2	14	3	4	18	2	14	3
plaintext	8	13	21	0	3	4	0	19	3	0	22	13	14
ciphertext	10	1	24	4	21	6	14	22	7	18	24	1	17

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- ▶ Encryption is achieved by performing the addition

$$c_i = m_i + k_i \bmod 26,$$

where m_i is the i th letter of the message and k_i is the i th letter of the keyword repeated over and over again.

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- ▶ A few people were involved in the cracking of this cipher, including quite a famous name in computing history.

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 - ▶ ANYVGYSTYNRPLWH...

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 - ▶ **A**NYVG**Y**STYN**R**PLWH. . .
 - ▶ These letters must have used the same row of the Vigenère square.

Breaking Vigenère

ZSHRSNAYEHVRHIUIZZQZXHWEFLXPOJFCXEFJAJMLSEURXXSVZXAGSEFYKCHYMXMLWJISKPRN
MWUIWESATXQYQHDISEXCTRRTXSLIZPNCBRHVXPBKSEOILKFVMXXVHYMRFEBJMRWCSKMWFSEFK
MPTWVZESPRHYMXTWAVZFNWWVPXAIAJQPOIGRNSNXHYQMKZOIUSNWQFZGXVBJFLXCKVDILGFL
FMGMGVPEGHGKGBIRGQVAEDJMPFSGKMWGEFIAAECOJMQTRKZFLTQWTDLSLGGCQQBKVKEGKYHZ
ZMLIHYQXKEBJUIGXQIQEMYFVEXAEHJIEKQOEPQNPBZBPRMBRPVHTCWIEMIFNUXAMBWURBXST
AQIPOTQRVCAVZAXRHKAEGHTIASOIFKTMLKZFNITFCLFXAIWIXMMXZVMJYEWIEWXVSEQMGXVV
UVTWGLDEGGSFRXAIWIIQQIMFVAZXVARFXXVWUKUWISGJUFEIHYMXMLSZZJNWCIUENRRVDXAIASZ
OVHWQFBIWSHYQWTQSEASGIURHITXVFGKAXHFFLXSZUQVPSFCPWHJGGMGXEGJAYKGSJAJAYAR
ZHTRUVDKXVFGKAXCWLXQCEXCMSRZEQBWGKTIBHSRAJEMTVGTHRHYQQTWDBSLWWSXIHVWD
BVHFOSXIBXWJOYKMCLEHXVSTMPPEWCDQSYXVVYIGXOCTEUMHJAJMLCJQHXTTOIFIWHOPEEMQCJ
FXXVFVEXKMOCYIGJOEOMXHHYQVXQWXTXUICKTIKQSEGTHRARDWIIFYMTLMBWQVBSFKAXAIAJ
QPOIGRZHKIOUKXHASCOSFIODUWLMCEMVRIBKQVIVWJQCXXOTDSLWHYQKNPTFRWIEQVYMGHGK
TEMEFVFSHYFDURWWOJAYKWOIQXHXVFEIHJHYQFXEGKEXAEHGQVBWVZZXXPZVOXLZOJFEGHQF
APTRRLZWRQDRFLXXWTDIZEFUQHMLWJQEKKVNUXAIBMUSNWSPQWTRRJXSPPMRZHLVFXCWSN
FLXMFGXEGWOXMMGWHLE

- Assume we know the key length: $k = 6$. We'll look into how to figure this out later.

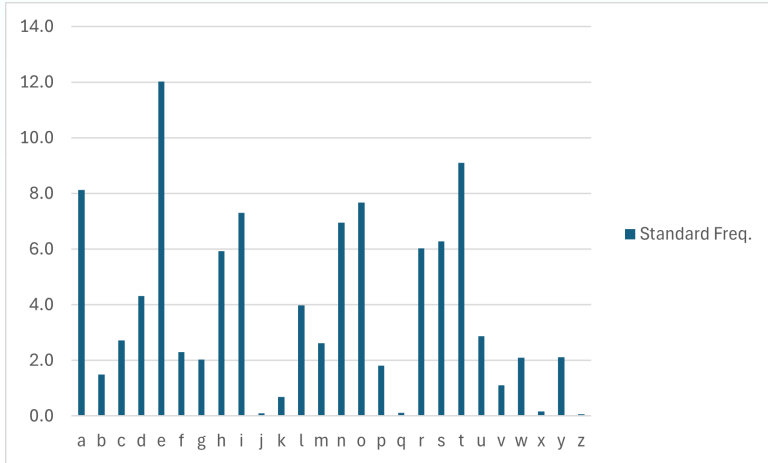
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MWUIWESATXQYQHDISEXCTRRTXSLIZPNCBRHVXPBKSEOILKFVMXXVHYMRFEBJMRWCSKMWFSFK
MPTWVZESPRHYMXTWAVZFNWWVPXAIAJQPOIGRNSNXHYQMKZOIUSNWQFZGXVBJFLXCKVDILGFL
FMGMGPPEGHGKGHBIRGQVAEDJMPFSGKMWGEFIAAECOJMQTRKZFLTQWTDLSGCGQQBKVKEGKYHZ
ZMLIHYQXKEBJUIGXQIQEMYFVEXAEHJIEKQOEPQNPBZBPRMBRPVHTCWITEMIFNUXAMBWURBXST
AQIPOTQRVCAVZAXRHKAEGHTIASOIFKTMLKZFNITFCLFXAIWIXMMXZVMJYEWIEWXVSEQMGXVV
UVTWGLDEGGSFRXAIWIQQIMFVAZXVARFXXVWKUWISGJUFEIHYMXMLSZZJNWCIUENRRVDXAIAZ
OVHWQFBIWSHYQWTQSEASGIURHITXVFGKAXHFFLXSZUQVPSFCPWHJGGMGXEGJAYKGSJAJAYAR
ZHTRUVDSKXVFGKAXCWFLXQCEXCMSRZEQBWGKTIBHSRAJEMTVGTHRHYQQTWDBSLWWSXIHVWD
BVHFOSXIBXWJOYKMCLEXHVSTMPEWCDQSYXVVYIGXOCTEUMHJAJMLCJQHXTTOIFIWHOPEEMQCJ
FXXVFVEXKMOCYIGJOEOMXHHYQVXQWXTXUICKTIKQSEGTHRARDWIIFYMTLMBWQVBSFKAXAIAJ
QPOIGRZHKIOUKXHASCOSFIODUWLMCEMVRIBKQVIVWJQCXXOTDSLWHYQKNPTFRWIEQVYMGHGK
TEMEFVFSHYFDURWWOJAYKWOIQXHXVFEIHJHYQFXEGKEAXAHEGQVBWVZZXXPZVOXLZOJFEGHQF
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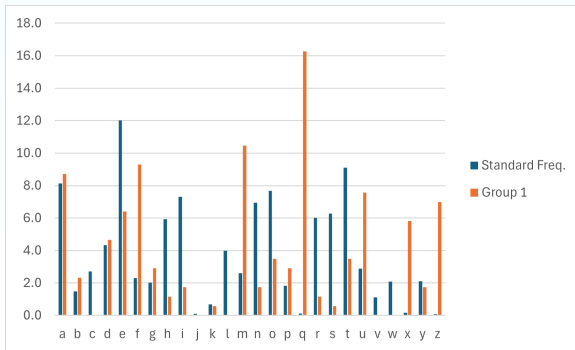
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ZSHRSNAYEHVRHIUIZZQZXHWEFLXPOJFCXEFJAJMLSEURXXSVZXAGSEFYKCHYMXMLWJISKPRN
MWUIWESATXQYQHDISEXCTRRTXSLIZPNCBRHVXPBKSEOILKFVMXXVHYMRFEBJMRWCSKMWFSFK
MPTWVZESPRHYMXTWAVZFNWWVPXAIAJQPOIGRNSNXHYQMKZOIUSNWQFZGXVBJFLXCKVDILGFL
FMGMGPVEGHGKGHBIRGQVAEDJMPFSGKMWGEFIAAECOJMQTRKZFLTQWTDLSLGCQQBKVKEGKYHZ
ZMLIHYQXKEBJUIGXQIQEMYFVEXAEHJIEKQOEPQNPHZBPRMBRPVHTCWIEMIFNUXAMBWURBXST
AQIPOTQRVCAVZAXRHKAEGHTIASOIFKTMLKZFNITFCLFXAIWIXMMXZVMJYEWIEWXVSEQMGXVV
UVTWGLDEGGSFRXAIWIIQIMFVAZXVARFXXVWKUWISGJUFEIHXYMXMLSZZJNWCIUENRRVDXAIAS
OVHWQFBIWSHYQWTQSEASGIURHITXVFGKAXHFFLXSZUQVPSFCPWJGGMGXEGJAYKGSJAJAYAR
ZHTRUVD SKXVFGKAXCWFLXQCEXCMSRZEQBWGKTIBHSRAJEMTVGTHRHYQQTWWDBSLWWSXIHVWD
BVHFOSXIBXWJOYKMCLEXHVSTMP EWCDQSYXVVYIGXOCTEUMHJAJMLCJQHXT OIF IWHOPEEMQCJ
FXXVFVEXKMOCYIGJOEOMXHHYQVXQWXTXUICKTIKQSEGTHRARDWIIFYMTLMBWQVBSFKAXAIAJ
QPOIGRZHKIOUKXHASCO SFIODUWLMCEMVRIBKQVIVWJQCXXOTDSLWHYQKNPTFRWIEQVYMGHGK
TEMEFVFSHYFDURWWOJAYKWOIQXHXVFEIHJHYQFXEGKEXAEHGQVBWVZZXXPZVOXLZOJFEGHQF
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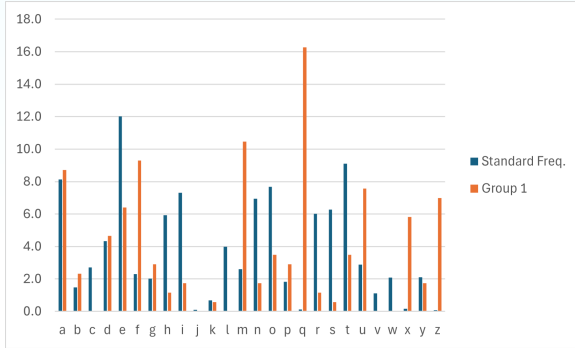
Patterns in the Standard Frequencies



Letter Group 1

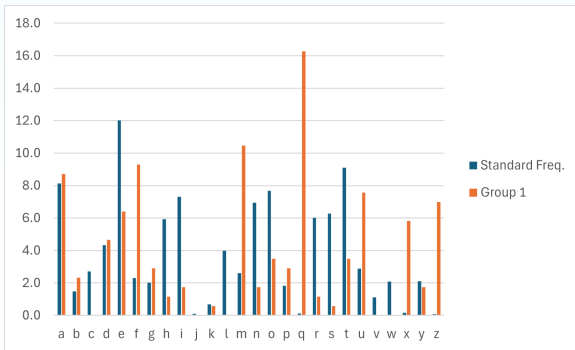


Letter Group 1



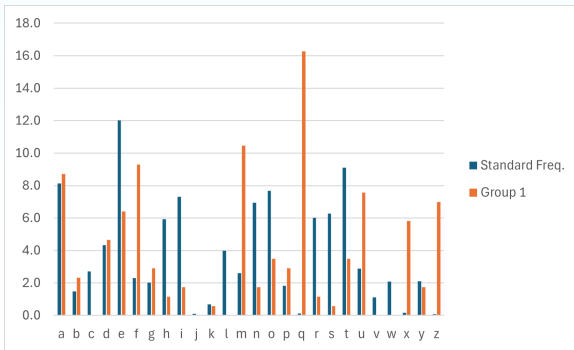
- Each group has been shifted by the same value: a Caesar cipher.

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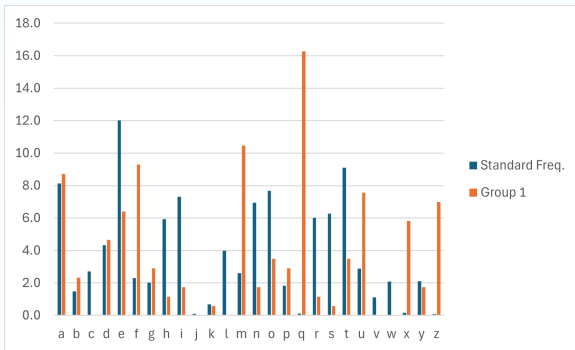
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- ▶ The charts will look the same, just shifted by a number of places.

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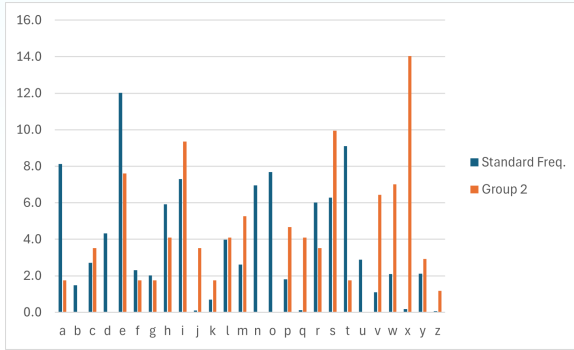
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- ▶ There is a gap of 4 letters from a to e, with e having the higher frequency.

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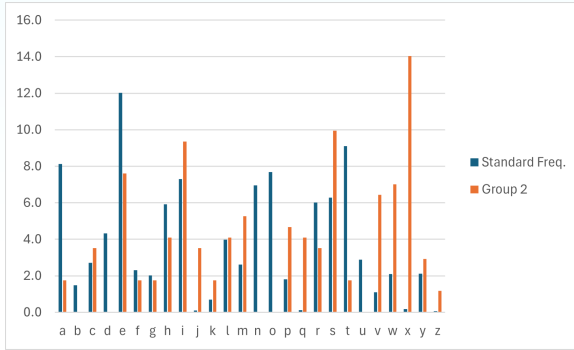


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- ▶ There is a gap of 4 letters from a to e, with e having the higher frequency.
- ▶ We can find this same gap, or other patterns, and deduce that the likely shift is a to m: shift value 12.

Letter Group 2

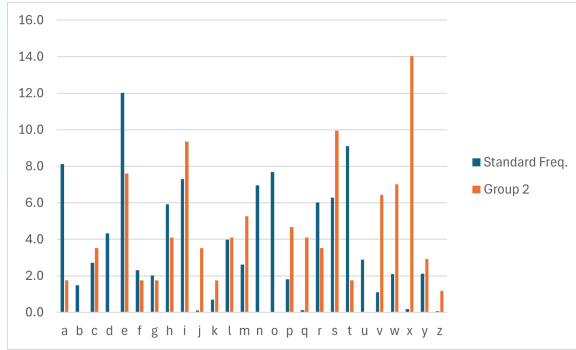


Letter Group 2



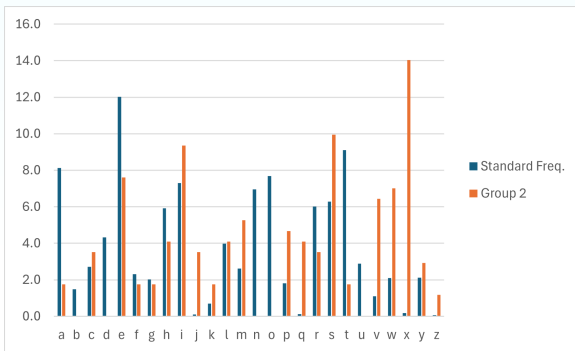
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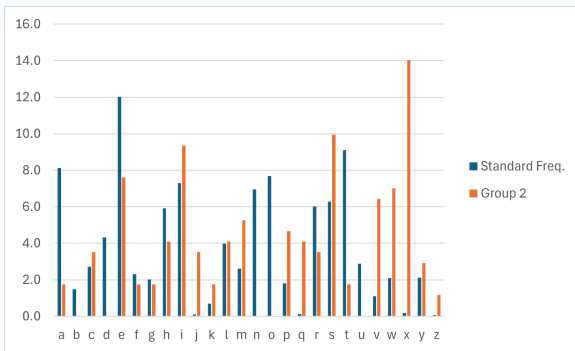
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- ▶ Each group has been shifted by the same value: a Caesar cipher.
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- ▶ The charts will look the same, just shifted by a number of places.
- ▶ There looks to be a gap like before from s to x, but the gap is 5 so can't be the gap from a to e.
- ▶ Instead we can choose the gap e to i and deduce that the likely shift is a to e: shift value 4.

Other Letter Groups

- ▶ We can continue this analysis for each of the groups. The key length is 6 so there will be six groups to consider.

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 - ▶ Group 6: shift 17.

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 - ▶ Group 6: shift 17. key letter r.
- ▶ So the keyword appears to be meteor and we can then attempt to decrypt the text.

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noone would have believed in the last years of the nineteenth century that this world was being watched keenly and closely by intelligences greater than mans and yet as mortal as his own that as men busied themselves about their various concerns they were scrutinised and studied perhaps almost as narrowly as a man with a microscope might scrutinise the transient creatures that swarm and multiply in a drop of water with infinite complacency men went to and fro over this globe about their little affairs serene in their assurance of their empire over matter it is possible that the infusoria under the microscope do the same noone gave a thought to the older worlds of space as sources of human danger or thought of them only to dismiss the idea of life upon them as impossible or improbable it is curious to recall some of the mental habits of those departed days at most terrestrial men fancied there might be other men upon mars perhaps inferior to themselves and ready to welcome a missionary enterprise yet across the gulf of space minds that are to our minds as ours are to those of the beasts that perish intellects vast and cool and unsympathetic regarded this earth with envious eyes and slowly and surely drew their plans against us

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- ▶ This forms the basis of a **Kasiski attack**.
- ▶ Longer messages are more likely to yield to such an attack as there will be more repeated segments.

Breaking Vigenère

ZSHRSNAYEHVRHIUIZZQZXHWEFLXPOJFCXEFJAJMLSEURXXSVZXAGSEFYKCHYMXMLWJISKPRN
MWUIWESATXQYQHDISEXCTRRTXSLIZPNCBRHVXPBKSEOILKFVMXXVHYMRFEBJMRWCSKMWFSEFK
MPTWVZESPRHYMXTWAVZFNWWVPXAIAJQPOIGRNSNXHYQMKZOIUSNWQFZGXVBJFLXCKVDILGFL
FMGMGVPEGHGKGHBIRGQVAEDJMPFSGKMWGEFIAAECOJMQTRKZFLTQWTDLSGCGQQBKVKEGKYHZ
ZMLIHYQXKEBJUIGXQIQEMYFVEXAEHJIEKQOEPQNPBZBPRMBRPVHTCWIEMIFNUXAMBWURBXST
AQIPOTQRVCAVZAXRHKAEGHTIASOIFKTMLKZFNITFCLFXAIWIXMMXZVMJYEWIEWXVSEQMGXVV
UVTWGLDEGGSFRXAIWIIQQIMFVAZXVARFXXVWKUWISGJUFEIHYMXMLSZZJNWCIUENRRVDXAIAX
OVHWQFBIWSHYQWTQSEASGIURHITXVFGKAXHFFLXSZUQVPSFCPWHJGGMGXEGJAYKGSJAJAYAR
ZHTRUVDSKXVFGKAXCWFLXQCEXCMSRZEQBWGKTIBHSRAJEMTVGTHRHYQQTWDBSLWWSXIHVWD
BVHFOSXIBXWJOYKMCLEXHVSTMPPEWCDQSYXVVYIGXOCTEUMHJAJMLCJQHXTOIFIWHOPEEMQCJ
FXXVFVEXKMOCYIGJOEOMXHHYQVXQWXTXUICKTIKQSEGTHRARDWIIFYMTLMBWQVBSFKAXAIAJ
QPOIGRZHKIOUKXHASCOSFIODUWLMCEMVRIBKQVIVWJQCXXOTDSLWHYQKNPTFRWIEQVYMGHGK
TEMEFVFSHYFDURWWOJAYKWOIQXHXVFEIHJHYQFXEGKEXAEHGQVBWVZZXXPZVOXLZOJFEGHQF
APTRRLZWRQDRFLXXWTDIZEFUQHMLWJQEKKVNUXAIBMUSNWSPQWTRRJXSPPMRZHLYFVXCWVSN
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- ▶ We've narrowed it down, but that's still a lot of options.

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ZSHRSNAYEHVRHIUIZZQZXHWEFLXPOJFCXEFJAJMLSEURXXSVZXAGSEFYKCHYMXMLWJISKPRN
MWUIWESATXQYQHDISEXCTRRTXSLIZPNCBRHVXPBKSEOILKFVMXXVHYMRFEBJMRWCSKMWFSFK
MPTWVZESPRHYMXTWAVZFNWWVPXAIAJQPOIGRNSNXHYQMKZOIUSNWQFZGXVBJFLXCKVDILGFL
FMGMGVPEGHGKGBIRGQVAEDJMPFSGKMWGEFIAAECOJMQTRKZFLTQWTDLSGCGQQBKVKEGKYHZ
ZMLIHYQXKEBJUIGXQIQEMYFVEXAEHJIEKQOEPQNPBZBPRMBRPVHTCWIEMIFNUXAMBWURBXST
AQIPOTQRVCAVZAXRHKAEGHTIASOIFKTMLKZFNITFCLFXAIWIXMMXZVMJYEWIEWXVSEQMGXVV
UVTWGLDEGGSFRXAIWIIQQIMFVAZXVARFXXVWKUWISGJUFEIHYMXMLSZZJNWC IUENRRVDXAIAX
OVHWQFBIWSHYQWTQSEASGIURHITXVFGKAXHFFLXSZUQVPSFCPWHJGGMGXEGJAYKGSJAJAYAR
ZHTRUVDSKXVFGKAXCWFLXQCEXCMSRZEQBWGKTIBHSRAJEMTVGTHRHYQQTWDBSLWWSXIHVWD
BVHFOSXIBXWJOYKMCLEXHVSTMPPEWCDQSYXVVYIGXOCTEUMHJAJMLCJQHXTTOIFIWHOPEEMQCJ
FXXVFVEXKMOCYIGJOEOMXHHYQVXQWXTXUICKTIKQSEGTHRARDWIIFYMTLMBWQVBSFKAXAIAJ
QPOIGRZHKIOUKXHASCOSFIODUWLMCEMVRIBKQVIVWJQCXXOTDSLWHYQKNPTFRWIEQVYMGHGK
TEMEFVFSHYFDURWWOJAYKWOIQXHXVFEIHJHYQFXEGKEXAEHGQVBWVZZXXPZVOXLZOJFEGHQF
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MWUIWESATXQYQHDISEXCTRRTXSLIZPNCBRHVXPBKSEOILKFVMXXVHYMRFEBJMRWCSKMWFSEFK
MPTWVZESPRHYMXTWAVZFNWWVPXAIAJQPOIGRNSNXHYQMKZOIUSNWQFZGXVBJFLXCKVDILGFL
FMGMGVPEGHGKGBIRGQVAEDJMPFSGKMWGEFIAAECOJMQTRKZFLTQWTDLSGCGQQBKVKEGKYHZ
ZMLIHYQXKEBJUIGXQIQEMYFVEXAEHJIEKQOEPQNPBZBPRMBRPVHTCWIEMIFNUXAMBWURBXST
AQIPOTQRVCAVZAXRHKAEGHTIASOIFKTMLKZFNITFCLFXAIWIXMMXZVMJYEWIEWXVSEQMGXVV
UVTWGLDEGGSFRXAIWIIQQIMFVAZXVARFXXVWKUWISGJUFEIHYMXMLSZZJNWCIUENRRVDXAIAZ
OVHWQFBIWSHYQWTQSEASGIURHITXVFGKAXHFFLXSZUQVPSFCPWHJGGMGXEGJAYKGSJAJAYAR
ZHTRUVDSKXVFGKAXCWFLXQCEXCMSRZEQBWGKTIBHSRAJEMTVGTHRHYQQTWDBSLWWSXIHVWD
BVHFOSXIBXWJOYKMCLEXHVSTMPPEWCDQSYXVVYIGXOCTEUMHJAJMLCJQHXTOIFIWHOPEEMQCJ
FXXVFVEXKMOCYIGJOEOMXHHYQVXQWXTXUICKTIKQSEGTHRARDWIIFYMTLMBWQVBSFKAXAIAJ
QPOIGRZHKIOUKXHASCOSFIODUWLMCEMVRIBKQVIVWJQCXXOTDSLWHYQKNPTFRWIEQVYMGHGK
TEMEFVFSHYFDURWWOJAYKWOIQXHXVFEIHJHYQFXEGKEXAEHGQVBWVZZXXPZVOXLZOJFEGHQF
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[illegible]

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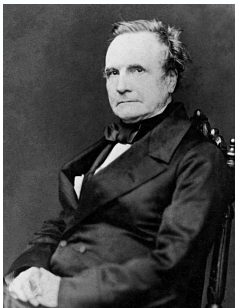
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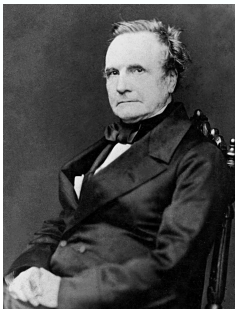
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- ▶ If we analyse the factors in the table, the obvious candidates for key lengths are 2, 3, 4, and 6.
- ▶ Key lengths of 2, 3 or 4 are quite short, so we rule them out. (We may have to come back to them.) The key length is likely to be 6 and as we found out, the actual keyword was meteor.

Who broke the unbreakable cipher?

- ▶ Our method is known as a Kasiski attack, but somebody else had got there first.

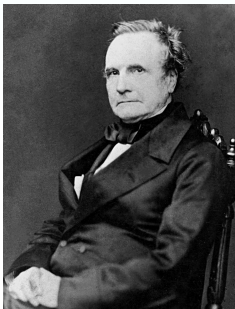


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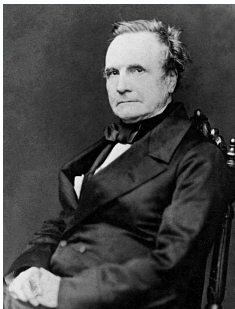
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- ▶ German cryptographer and archaeologist Friedrich Kasiski attacked the problem in 1863.
- ▶ But Charles Babbage had cracked it in 1854. The British government wanted to keep it secret in the Crimean War.
- ▶ We know Babbage better as being the originator of the programmable computer, having designed the Analytical and Differences Engines.

Tutorials

In the tutorial this week we will:

- ▶ Create a spreadsheet to perform Vigenère encryption.
- ▶ Use a premade spreadsheet to perform a Kasiski-style attack on Vigenère encryption.