Cryptography during the two world wars, and wrap-up of classical ciphers. Math 4440/5440.

◆□▶ ◆□▶ ◆ □▶ ◆ □▶ ○ □ ○ ○ ○ ○

First World War German Cipher: ADFGVX Cipher



Plaintext: ATTACK AT DAWN

Step 1: DG XG XG DG AA DD DG XG FX DG FD FA Ciphertext: GGDGGAXDDXDFDXADFFGGAGXD

(日本)(同本)(日本)(日本)(日本)

Comments

	A	D	F	G	V	Х		3	4	2	1
Α	с	0	8	Х	f	4	-	D	G	Х	G
D	m	k	3	а	z	9		Х	G	D	G
F	n	w	1	0	j	d		А	А	D	D
G	5	s	i	у	h	u		D	G	Х	G
V	р	Ι	v	b	6	r		F	Х	D	G
Х	e	q	7	t	2	g		F	D	F	А

- 1. The thing on the left is a Polybius square; dates back to ancient greece.
- 2. It's purpose was coding theory: reduce the number of symbols in the alphabet from 26 to 5.
- 3. Long-distance signalling (e.g. holding up 1-5 firey torches) was less prone to error with a smaller alphabet.
- 4. Message length increases but error rate decreases.

Some clues to cryptanalysis (French broke it)



- 1. Because the keylength (3421) is even here, the letters in one column are either all column headers or all row headers.
- 2. Column header D has a different frequency than row header D.
- 3. Use frequency analysis to identify the likely columns.
- 4. Pair columns (e.g. put 3 next to 4) and do frequency analysis on the digraphs (DG, XG etc.) to see if the pairing is correct.



Wartime Enigma Machine



	AC	h	tur	1g!	Sdjlü[[e	Imit	tel ò	ütle	n nidi	tuni	oer[e]	prt in	Jeint	esha	no Jo	llen.	Bur	scimi	ettp	105 11	no fr	infilter	I			
	lonats- 100		W e I	3 e n l a g		Ring	ftellu	ng	en i	ber Un	5 Achron	1 e	ets v		e r	b i i eir	ð u Stech	erbrett	7		•	10	1.500	henng	ruppei	1
	E			W		1.2	rc.	2.1					SZ	OT	DV	KU	FO	мү	EW	JN	11	LQ	wny	dgy	exb	rzg
10	31				11	05	26	62					15	EV	MX	RW	DT	UZ	JQ	40	CH	NY	1 K U I	acw	zsi	#30
4.10	30		×			12	20	02	КМ	XA	PZ	00	DJ	AT	CV	10	ER	QS	LW	P2	FN	BH	ioc	acu	0 VW	WV
10	14					05	00	14	DI	CN	BR	PV	CR	FV	AI	DK	OT	P.M	EU	BX	LP	GJ	115	cld	ude	rzł
39	20	1.		1	111	11	03	07	1.7	EO	HS	UW	DY	IN	BV	OR	MA	LO	PP	НТ	ЕX	UW	woj	fbh	vct	ui
4.6	121			111/	Nr.	17	22	10		-			VZ	AL	RT	ко	co	E1	ВJ	DU	FS	HP	xle	gbo	uev	L XI
44	20		1	11		0.9	26	12	100				OR	PV	AD	IT	PK	HJ	LZ	NS	EQ	CW	ouc	uhq	uew	ui
940	120		N.		iv	05	18	14		7.152	2000		TY	AS	0%	ΚV	JM	DR	НΧ	0L	C2	NU	kpl	r#1	vci	tle
140	24					24	12	04					QV	FR	AK	EO	DH	CJ	NZ	SX	0N	LT	ebn	rwm	udf	tie
549	123			11	v	01	00	21	111		DV	01.	FJ	ES	IM	RX	LV	ΛY	00	BO	WZ	CN	Jac	acx	mwe	wve
040	1 22		1	v	i	13	05	19	PT	OY	87	CH	RU	HL	FY	05	θZ	DM	¥.M.	CE	TV	NX	Jpw	del	mwI	wv:
640	20			11	v	24	01	10	1.1			DW	DF	20	QZ	NU	RY	SV	JL	0 X	BE	TW	jqd	cel	nvo	110
640	10		v	111	1	17	25	20	MR	VU	DQ	1.4	OX.	PR	FH	WY	DL	CM	YE	TZ	15	61	101	1.px	JWE	115
640	15	1	iv	11	v	15	23	26					EJ	OY	IV	AQ	XW	FX	NT	PS	ro	BD	-152	*ow	vej	Vei
840	1		1	IV	1!	21	10	06	1	-	_	-	IR	KZ	LS	EN.	ov	01	QX	AP	JP	BU	mae	121	THE	
649	tie	5	v	11	111	08	16	13					HM	10	DI	NR	BY	XZ	05	PU	TP	MT	L dw	hri	soh	WVE
849	1	5	11	1V	1	01	03	07					DS	HY	MR	6×	PY	AJ	BQ	00	11	NV	im	103	tiv	xtk
649	1	4	IV	1	v	15	11	05	AT	BT	MV	HU	I OM	JR	KS	11	HZ.	PL	AA WW	CW.	FT	CT	7.07	dez	gio	rye
849	11	3	1	ill	11	13	20	03	FW	EL	DO	KN	LY	AG	KM	BR	10	30	IT	na	IL.	PW	zdy	rkf	tjw	xti
649	1	2	v	1	IV	18	10	07	RZ.	00	CP	SX	i MU	Br	ND ND	PW	PM	BO	F7	OT	DX	JV	zes	riy	soi	wvh
841	1	1	11	IV	111 -	02	26	15					KR	10	nn vs	011	HW	PT	00	VX	FZ	EN	Irc	zbx	vbm	rxo
849	2	0	ш	v	11	23	21	01					: DR	BS	LN	KT	AP	IU	DW	но	RV	JZ	edj	eyr	vby	tlh
841	Ð	9	۷.	. 1		16	04	0	-				PT	NO	SY	CU	BZ	AH	EL	TX	DO	KP	yiz	dha	ekc	tli
641	9	8	1V.	н	v	13	5 19	2					UX.	12	HN	BK	00	CP	FT	JY	MW	AR	lan	dgb	zsj	wbi
841	9	7_	1	1V	п	. 0	0.						DQ	GU	BW	NP	HK	AZ	CI	PO	JX	۷۷	120	cft	zsk	wbj
64	9	6_	111	1	V	2	0.0	2 2	IL	AF	EU	но	MV	CL	OK	QQ	BI	FU	HS	PX	NW	EY	lju	cdr	iye	waj
64	9	5	V	11	10	10	1 2	1 0	QT	W 2	KV	GM	. AC	BL	02	EK	Q¥	OP	SU	DH	JM	TX	150	zby	vey	ujo
84	9	4.	II N	IV	1	1	0 1	0	BP	NF	DX	CS	* KR	MP	CN	BF	EH	DZ	IW	AV	0J	LO	lap	owd	iwu	widk
04	9	2	11	v	I	1	6 1	4 0	2				BN	HU	EO	PY	KQ	CP	os	JW	AI	v2	aqd	ody.	rio.	wirv
0.9		.×	14			10							DP	RM	N2.	CK	OV	2H	AP	UY	SW	10	I Kg1	Cui I	614	1.0.04

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	E											1	2	DV.	KU	FO	MY	EW	JN	13	LQ	wny	dgy	exb	rzg
8	31	1	V	in l	14	04	14					16	FU	MY	RW	DT	UZ	JO	40	CH	NY	k t l	acw	zsi	¥20
8	30	IV	111	11	CO	26	02	811	6.X	P2	00	15	10	CV	10	50	05	LW	P2.	FN	BH	ioc	acn	OVW	wvd
9	29	111	11	1	12	24	03	DI	CN	HP	PU	CP	PH	AT	DE	OT	NO	EU	BX	LP	0J	1 rb	cld	ude	rzh
19	28	11	111	V	05	96	10					DY	1.1	BV	OR	AN.	1.0	PP	HT	EX	UW	woj	fbh	vet	uis
19	27	111	1	11	11	03	07	LT	EQ	HS	UW	. D1	10	DV	VA	co	11	RI	DU	PS	HP	xle	gbo	uev	rxe
16	26	1	IV	. V	17	22	19						AL		1.0	PV	111	1.7	NS	EO	CW	ouc	uhq	uew	uit
19	25	IV	ш	1	03	25	12					OR	1.0	AD	21	11	DR	HY	61.	C2.	NU	kpl	rwl	vci	tiq
49	24	v	1	IV	05	18	14	1.3				I TI	10		FO	DH	CI	W2	SX	ON	LT	ebn	rwm	udf	t10
49	23	11	11	1	24	12	04					QV	PC	TH	D Y	LV	AY	011	BO	WZ	CN	190	acx	mwe	wve
40	22	11	11	v	01	69	21	10	AS	DV	OL	I PJ	UI.	PY	05	07	DM	AW	CE	TV	NX	Jpw	del	mwf	wvf
40	21	1	v	11	13	05	19	FT	ox	EZ	CH	Inp	20	07	AU	RY	SV	JL	ox	BE	TW	jqd	cef	nvo	ysh
49	20	111	1V	v	24	01	10	MR	KN	BQ	PW	OX	PP	FH	WY	DL	CM	AE	72	15	GI	idf	fpx	JWE	tig
49	19	V	111	1	17	25	20	1.1.				181	OY	TV	A0	XX	FX	MT	PS	LU	BD	158	"bw	vej	rxn
49	18	IV	11	· v	15	23	20					TD		T.S.	EM.	ov	OY	ox	AP	JP	BU	mae	hzi '	SOE	ysi
349	17	1.1.	IV	12	21	10	00			-			10	DT	NR	BY	2.2	05	PU	FQ	CT	tdp	dhb	fkb	uiv
149	16	V	11	m	08	16	13					DS	HY	MR	0W	LX	AJ	BQ	co	IP	NT	1 dw	hzj	soh	wvg
340	15	11	IV.	1	01	03	0/					iow	JR	KS	IY	HZ	PL	AX	BT	CQ	NV	imz	noa	tjv	xtk
349	14	. 1V	1	v	15	11	03	IA	вт	MA	HU	LY	AG	KM	BR	19	JU	HV	SW	ET	CX	zgr	dgz	gjo	ryq
649	13	1		n	113	20	03	FW	EL	DO	KN	MU	BP	CY	RZ	KX	AN	JT	DG	1L	PW	zdy	rkf	tjw	xt1
649	12	- V	15	10	10	26	16	RZ	00	CP	SX	KN	UY	HR	PW	PN	во	EZ	QT	DX	JV	202	rjy	soi	wvh
049	11	1 11	10	111 -	1 22	20	01					LR	IK	MS	QU	Н₩	PT	00	VX	FZ	EN	lrc	zbx	vbm	TXO
649	.10	m	Y	1.	14	0	02					' QY	BS	LN	KT	AP	IU	DW	но	RV	JZ	edj	eyr	Vby	tin
649	19	- V		· · · ·		10	0.5	-				FI	NQ	SY	CU	BZ	HA	EL	TX	DO	KP	yiz	dha	ekc	th
649	8	- 11	n	v II	1	0	2					. UX	12	HN	BK	QQ	CF	FT	JY	MW	AR	lan	dgb	25)	WO1
049	17	- 1	14	W	1	1 12	14					. DQ	GU	BW	NP	HK	A2	CI	PO	JX	VY	120	cit	ZSX	woj
041	1.0	- "	1	IV	12	3 0	2	IL	AP	EU	но	MV	CL	OK	QQ	BI	FU	HS	PX	NW	EY	1 ju	car	1 ye	-aj
0.91	1	1	11	1	lô	4 2	0	QT	W2	KV	. GN	. AC	BL	02	EK	QX	OP	SU	DH	JM	TX	150	209	v cy	wak
041		- 1 W	1	i	1	9 1	1 0	BF	NE	DX	CS	· KR	MP	CN	BF	EH	DZ	IW	AV	OJ	LO	lap	bwo	ivf	ytd
041		i iv	v	1	11	6 1	4 0	2				BN	HU	EO	PY	KQ	CP	05	JW	AI	VZ	aqa	adr.	ain.	with
0.41			S		1.							DP	BM	NZ	CK	0 Y	210	AP	UY	SW	20	1 681		0.4.4	

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	E						trees.		en l	ber Um	kehrm	olye		2	,		3	6	7		9	10			1	1200
19	31		-			14	69	24					SZ	07	DV	KU	FO	MY	EW	JN	11	LQ	wny	dgy	620	TZE
19	3	80	` +		VC	05	26	62					15	EV	МΧ	RW	DT	UZ	10	V0	CH	NY	REI	acw	251	*31
49	2	IL	ノレ	U	13	12	24	03	KM	XA	PZ	00	DJ	TA	CV	10	ER	QS	LW	P2	FN	BH	100	acn	OVW.	wve
05	20	11			V	05	90	16	DI	CN	BR	PV	CR	FV	AI	DK	0T	NQ	EU	BX	LP	01	115	cld	ude	121
40	27	111		1	112	11	03	07	LT	EQ	HS	UW	DY	IN	BV	OR	AM	LO	PP	НТ	EX	0W	woj	Ibn	vet	u13
26	24			iv.	v	17	22	19	1000				V2	AL	RT	KO	CO	E1	BJ	DU	FS	HP	xle	gpo	uev	FXE
40	20	inv.				08	25	12					OR	PV	AD	IT	PK	HJ	LZ	NS	EQ	CW	ouc	uhq	uew	U11
40	20	1 v			iv	05	18	14		7.11.27			TY	AS	٥w	ΚV	JM	DR	HX	GL	C2	NU	k p l	rwl	ve1	tic
10	24	1				24	12	04					QV	FR	AK	EO	DH	CJ	MZ	SX	ON	LT	ebn	rwm	udi	tie
10	20	1 11		IV	v	01	09	21	10	AS	DV	01.	FJ	ES	IM	RX	LV	٨Y	00	BO	WZ	CN	205	acx	mwe	wve
140	22	1 1		v	11	13	05	19	100	01	87	CH	RU	HL	F٢	05	C Z	DM	¥.M.	CE	TV	NX	7bm.	del	mwi	wvi
048	20	1 11		11	v	24	01	10	1.1			DW	DF	10	QZ	ΑU	RY	sv	JL	0 X	BE	TW	jqd	cel	nvo	y 51
640	10	1 V		111	1	17	25	20	MR	N.B	DQ		ox	PR	FH	WY	DL	CM	AE	72	15	GI	101	1.px	JWE	
040	10	1 1	;	11	v	15	23	26					EJ	OY	IV	AQ	XW	FX	NT	PS	ro	BD	158	©0₩	vej	
040	1.17			IV	12	21	10	05	1	12	_		IR	KZ	LS	EM.	ov	OY	QX	AP	JP	.80	mae	nzi	644	
840	ti	1 .	1	11	111	08	16	13					HM	10	DI	NR	BY	XZ	05	PU	FQ	CT	top	ano	rob	
840	1		1	IV	1	01	03	07					DS	HY	MR	0.8	ΓX	vj	BQ	co	IP	NT	Idw	nzj	+ 1 1	++1
640	1		v	1	v	15	11	05	TA	BT	MV	HU	I GM	JR	KS	IY	HZ.	PL	AX	BT	CQ	OY.	102	daa	gio	TVO
640			1	in	11	13	20	03	PW	FL.	DO	KN	LY	¥G	KM	BR	IQ	30	RV	5%	ET.	DW	2.61	nkf	tiw	xti
649		2 .	v	1.	IV	18	10	07	1.0	00	CP	C Y	MU	BP	CY	RZ	KX	AN	JT	DG	DY	TW	207	riv	soi	wyh
049		1	11	IV	111	02	26	15	RL	00	01	3.	KN	UY	HR	PW	FR	BO	52	Q1	DA D7	FN	110	Thy	vbm	TXO
845		0 1	111	v	17	23	1 21	01					LR	IK	MZ	QU	1.0	71	DV	NO	'RV	.12	edi	evr	vby	tlh
645		9	v	1	ш	16	04	0					QY	35	LN	A1	NI D2	10	FI.	71	DO	KP	viz	dha	ekc	tli
845	0	8	IV.	П	٧	13	3 19	9 2					FI	NQ.	51	DV	00	CP	FT	JY	MW	AR	lan	dgb	zsj	wbi
841	9	7	1	11	11	0	0	3 2	2				. 01	12		NP	HE	42	CI	PO	JX	VY	120	cft	zsk	wbj
841	0	6	111	I	۷	1	1, 18	8 1.	IL	AP	EU	HO	: DQ	00	OX	00	BT	FU	HS	PX	NW	EY	1 ju	cdr	iye	waj
64	9	5	v	11	IV	2	3 0	2 2	07	WZ	KV	GM	AC	BL.	02	EK	OX	OP	SU	DH	JM	TX	150	zby	vcy	ujb
64	9	4	11	1V	1	0	4 2	1 0	2 2	ND	D	cs	. AG	NP	CN	BP	EH	DZ	IW	AV	OJ	LO	lap	owd	iwu	wak
64	9	3	v	1	11	1	9 1	1 0	5 57	nn		1 00	BN	HU	EO	PY	KQ	CP	os	JW	AI	V2	aqd	bdy.	iyf	xtd
64	0	2	1V	٧	1	11	0 1	4 0	2				DI			OV	av	HO		11.7	sw.	.10	kgl	'cdf	giq	WUY

 $5 \cdot 4 \cdot 3$

Ī	and's-	We	Izenlag	e	Ring	ftellu	ng	64	der Um	S	l e olar	ets e	e v	e'r	b i i en	i d i	i n g				10	1	frenng	ruppe	n
	E											1 C.7	2	DV.	KD	FO	MY	EW	JN	18	LQ	wny	dgy	exb	r z
49	31		•		4	04	14					36	E.I.	MY	2.2	57	112	10	40	CH	NY	ktl	acw	zsi	54
49	30	rn	τn	rs	22	26	02	811	6.X	P2	00	15	10	CV	10	50	05	LW	P2.	FN	BH	ioc	acn	OVW	WV
49	2			•••	12	24	03	DT	cu	-	PU	0.0	nu		DY	OT	NO	EU	BX	LP	OJ	115	cld	ude	rzi
49	28	11	111	v	05	80	10	DI	GI	DR		CR	T V	n1 n1	AP	1.1	1.0	pp	HT	EX	UW	woj	fbh	vet	ui:
49	27	111	1	1V	11	03	07	LT	EQ	HS	UW	. D1	10	DV	VA	co	11	RI	DI	PS	HP	xle	gbo	uev	r x
46	26	1	IV .					1000				. 0.0	DU	AD	TT	PF	HI	1.2	NS	EQ	CW	ouc	uhq	uew	ui
49	25	IV	ш	P I	in		r					. ev	10	OV	ww.	11	DR	нх	QL.	CZ.	NU	kp1	rwl	vci	t1
948	24	v	1			צו	ί.	1.2				1 01	00	AN	FO	DH	CJ	MZ	SX	ON	LT	ebn	rwm	udf	tl
49	23	11	11			-	•					QV	PE	TH	BY	LV	AY	011	BO	WZ	CN	190	acx	mwe	wv
40	22	11	11	v	01	69	21	10	AS	DV	OL	I DU	UI.	PY	05	07	DM	AW	CE	TV	NX	Jpw	del	mwf	wv
940	21	1	v	11	13	05	19	FT	ox	EZ	CH	Inp	20	07	AU	RY	SV	JL	ox	BE	TW	bpt	cef	nvo	ys
349	20	111	IV	v	24	01	10	MR	KN	BQ	PW	OX	PP	FH	WY	DL	CM	AE	72	15	GI	idf	fpx	JWE	t1
649	19	V	111	1	17	25	20	100				181	OY	TV	A0	XX	FX	MT	PS	LU	BD	1 s a	sbw	vej	гx
649	18	IV	11	· v	15	23	20					TR	. 82	LS	EM.	ov	OY	97.	AP	JP	BU	mae	hzi '	sog	y s
649	17	1.1.	IV	12	21	10	00					нм	10	DI	NR	BY	X.2	05	PU	FQ	CT	tdp	dhb	fkb	ui
649	16	V	11	m	08	10	13					DS	HY	MR	OW	LX	٨J	BQ	co	IP	NT	1 dw	hzj	soh	wv
649	15	11	. IV .	1	101	05	07					i QM	JR	KS	IY	HZ	PL	AX	BT	CQ	NV	imz	noa	tjv	xt
649	14	, IV	1	v	15			IV	вт	MV	но	LY		KM	BR	19	JU	HV	SW	ET	CX	zgr	dgz	gjo	ry
649	13	1-1-		II	113	10	03	FW	EL	DO	KN	MU	BP	CY	RZ	KX	AN	JT	DG	1L	PW	zdy	rkf	tjw	xt
649	12	- V	1	10	100	26	15	RZ	00	CP	SX	KN	UY	HR	PW	PN	во	EZ	QT	DX	JV	zea	rjy	soi	WV
649	11	1	11	111 -	27	21	0					LR	IK	MS	QU	Н₩	PT	00	VX	FZ	EN	lrc	zbx	vom	TX
844	1.10	1 m	,	111	11	0.	0					' QY	BS	LN	KT	AP	IU	DW	но	RV	JZ	edj	eyr	voy	
040				· · v	12	1 19	2	-				FI	NQ	SY	CU	BZ	HA	EL	TX	DO	KP	y12	dna	exc	wh
0.58					0	0 0	3 2					. UX	12	HN	BK	QQ	CP	FT	JY	MW	AR	lan	ago	250	wh
0.12		- 1	11	v	1	1 18	8 1-					. DQ	GU	BW	NP	HK	A2	CI	PO	JX	VY	120	cit	ive	
840	0 5	- v		IV	2	3 0	2 2	5 11	, AP	EU	NO	MV	CL	OK	QQ	BI	FU	HS	PX	NW	EI my	150	thy	YCY	uil
040		1 11	11	1	10	4 2	1 0	9 97	r wz	K	. ON	. AC	BL	02	EK	QX	OP	50	DH	JM	TX	150	owd	iwu	wal
84	0 3	v	1	11	1	9 1	1 0	5 B1	> NE	DX	CS		MP	CN	BF	EH	DZ	WI	AV	0.1	10	and	bdy	ivf	xti
641	0	I IV	v	I	1	6 1	4 0	2				BN	HU	EO	PY	KQ	CP	105	IIY	ew.	10	kel	cdf	gig	wu
		-			12	2 .						DF	8M	NZ	CK	9.4	911	DF.					100000000000000000000000000000000000000		_

 $5 \cdot 4 \cdot 3 \cdot 26^3$

1	500	Wel	Isenlag	e .	Ring	Itellui	19			5	1 0	ets e	e v	e t	b i i nir	i d i Stech	erbrett					13	henng	ruppe	n
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0	31				4	69	24					52	0.1	DV	NU	P.O	117	10	10	CH	NY	1 11	acw	251	*2
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19	28	11	111	V	05	80	16	DI	CN	BR	rv	CR	PV	AI	DK	01	20	50	DA NO	EY	nw	was	fbh	vet	uí
9	27	111	1	11	11	03	07	LT	EQ	HS	UW	DY	IN	BV	OR	AM	LO		nu	DE	HP	TIC.	cho	uev	rz
9	26	1	11									v2	AL	RT	xo	CU	51	BJ.	DO	FO	CW.	0.00	uho	uew	ui
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\$9	21	1	v	11	13	05	19	FT	ox	E2	CH	RU	HL	FI	0.5	0L	ev.	11.	01	BE.	TW	ind	cef	nvo	ys
49	20	111	1V	v	24	C							1	02	MY	DI	CM	18	97	15	GI	idf	fpx	JWE	t1
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49	17	1	IV	1!	21	10	00	-					10	DT	NR	BY	22	0.5	PU	FQ	CT	tdp	dhb	fkb	ui
49	16	V	11	111	08	16	13					DS	HY	MR	OW.	LX	AJ	BQ	co	IP	NT	ldw	hzj	soh	WV
49	15	11	. IV .	1	01	03	0/					igu	JR	KS	IY	HZ	PL	AX	BT	CQ	NV	imz	noa	tjv	xt
49	14	11	1	v	15	11	05	IA	BT	MA	HU	LY		KM	BR	10	JU	HV	SW	ET	CX	zgr	dgz	gjo	ry
140	13	1		n	113	20	03	FW	EL	DO	KN	1 MIL	BP	CY	RZ	KX	AN	JT	DG	1L	PW	zdy	rkf	tjw	xt
349	12	- V	15	1.	10	24	16	RZ	00	CP	SX	KN	UY	HR	PW	PN	во	EZ	QT	DX	JV	202	rjy	soi	WV
349	11	1 11	IV	III -	02	. 20	13					LR	IK	MS	QU	Н₩	PT	00	VX	FZ	EN	lrc	zbx	vbm	TX
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840		1 m	11	1	10	: 21	0	QT QT	WZ	KV	. GW	. AC	BL	02	EK	QX	OP	50	DH	JM	TX	150	owd	iwu	wa
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 $5 \cdot 4 \cdot 3 \cdot 26^3 \cdot 24! / (12!2^{12})$

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49	2			LU	13	12	24	03	KM	AX	PZ	00	DJ	TA	CV	10	ER	QS	LW	rz.	PR	nn ol	100	atd	ude	
49	28		11	111	V	05	08	16	DI	CN	BR	PV	CR	FV	AI	DK	OT	NO	EO	BX	Lr.	05	110	Chb	wet	
49	27		ш	1	11	11	03	07	LT	EQ	HS	UW	DY	IN	BV	OR	MA	ro	PP	HT	EX	UW	woj	100		
49	26		1	11	-	1			1000				V2	AL	RT	KO	co	El	BJ	DU	rs	nr	XIC	800	LIGW	
99	25		IV	111				_	1		- 10		OR	PV	AD	IT	PK	НJ	LZ	NS	EQ	CW	out	unq	uc.	110
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849	2	10	Ш	v	17	2	3 2	1 0	1				LR	10	1.N	KT	AP	TU	DW	HO	RV	JZ	edj	eyr	vby	tlh
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64	9	5	V	11	1/	1	23 (2 2	2 01	W2	K	OM.	AC	BL	02	EK	QX	OP	SU	DH	JM	TX	150	zby	vcy	ujb
64	9	4	11	17	1		14	0 0	B	NE	D	cs	· KB	MP	CN	BF	EH	DZ	IW	AV	OJ	LO	lap	owd	iwu	wak
64	9	3	V	1	11		14					1	BN	HU	EO	PY	KQ	CP	05	JW	IA	٧Z	aqd	bdy.	iyf	xtd
64	0	2	11	V	1		10	14 (14				DE		112	CV	ov	HO	AP	UY	SW	JO	kg1	cdf	giq	wuv

 $5 \cdot 4 \cdot 3 \cdot 26^3 \cdot 24! / (12!2^{12}) \cdot 26! / (10!6!2^{10})$

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9	2		ιU	10	12	24	03	NN.	~~	14	00	DJ	TA	CV	10	D.B.	45	50	E P	1 P	01	1 mb	cld	ude	rzh
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9	27	111	T	1V	11	03	07	LT.	EQ	HS	UW	DY	IN	BV	OR	MA	LO	rr	81	DE	UP	n l o	rbo	ney	TYP
9	26	1	11									v2	AL	RT	xo	Cu	14	BJ.	DO NC	FO	CW	0.00	uho	uew	uit
9	25	11	111		•		-	1			-	OR	PV	AD	IT	PK	HJ	LZ	N.S	EQ	N/I	kel	rel	vei	tic
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10	22	11	1V	V	01	69	21	10	AS	DV	OL	PJ	ES	IM	RA	114	DI		00	TV	NX	inw	del	mwf	wvf
40	21	1	v	11	13	05	19	PT	ox	EZ	CH	RU	HL	FI	05	0L	SV	11.	01	BE.	TW	ind	cef	nvo	ysh
40	20	111	1V	v	24	0							1	02	NU	DI	CM	IF	97	15	GI	idf	fpx	JWE	tig
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49	16	v	11	111	08	16	13	1				DS	NY	MR	OW	LX	AJ	BQ	co	IP	NT	1 dw	hzj	soh	wvg.
49	15	11	IV .	1	01	03	07	1.1						-							v	imz	noa	tjv	xtk
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649	8	- IV	п	V	1.		2 22					. UX	12	HN	BK	00	CP	FT	JY	MW	AR	1	nn	SI	
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0.41			ý	ï	1	6 1	4 02					BN	i HŲ	EO	PY	KQ	CP	os	JW	AI	VZ	aqa	ody	171	with
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 $5\cdot 4\cdot 3\cdot 26^3\cdot 24!/(12!2^{12})\cdot 26!/(10!6!2^{10})\cdot 26^3$

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8	2				4		03	DI	CN	RR	PV	CR	PV	AT	DK	OT	NO	EU	вх	LP	OJ	1 rb	cld	ude	rzh
9	28	11	III	v	05	96	10					DY	1.1	BV	OR	AN.	1.0	PP	HT	EX	UW	woj	fbh	vet	uis
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49	18	IV	11	· v	15			<u> </u>		~~		<u> </u>		LS	EM	ov	OY	QX	AP	JP	BU	mae	hzi '	SOE	ysi
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 $5 \cdot 4 \cdot 3 \cdot 26^3 \cdot 24! / (12!2^{12}) \cdot 26! / (10!6!2^{10}) \cdot 26^3 \simeq 150$ undecillion

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 $5\cdot 4\cdot 3\cdot 26^3\cdot 24!/(12!2^{12})\cdot 26!/(10!6!2^{10})\cdot 26^3\simeq 150$ undecillion 789 decillion

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 $5\cdot 4\cdot 3\cdot 26^3\cdot 24!/(12!2^{12})\cdot 26!/(10!6!2^{10})\cdot 26^3\simeq 150$ undecillion 789 decillion 931 nonillion

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 $5\cdot 4\cdot 3\cdot 26^3\cdot 24!/(12!2^{12})\cdot 26!/(10!6!2^{10})\cdot 26^3\simeq 150$ undecillion 789 decillion 931 nonillion 331 octillion

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0.10	1.6	- v		IV	2	0	2 25	IL	AP	EO	nc	MV	CL	OK	QQ	BI	FU	HS	rX	ILW.	LI	1 ab	a bu	VCV	wib	
840		1 11	11	1	0	2	1 05	QT	W2	K	GN	. AC	BL	02	EK	QX	OP	50	DH	JM	TX	150	owd	iwu	wak	
840		· v	1	11	119	1	1 00	BF	NB	DX	CS	. KB	MP	CN	BF	EH	DZ	IW	AV	0.1	10	and	hdy	ivf	xtd	
640		IV	v	I	10	5 1	4 03	2				BN	HU	EO	PY	KQ	CP	05	3.4	AL	10	kel	cdf	gig	wuv	
~ 34	100				100			201				DE		217	CK	0.V	210	AF.	UI	o M	~ ~ ~	- C -				

 $5 \cdot 4 \cdot 3 \cdot 26^3 \cdot 24!/(12!2^{12}) \cdot 26!/(10!6!2^{10}) \cdot 26^3 \simeq 150$ undecillion 789 decillion 931 nonillion 331 octillion 314 septillion

1	amots-	We	lienlog		Ring	ftellu	ng	en i	ber Um	5 skihras	1 0	ets e		e 'r	b i i	n d i n Steet	arbrett				10	1 San	henny	ruppe	n
	21	-	-			r.c	2:1					SZ.	OT	DV	KU	FO	мү	EW	JN	11	LQ	wny	dgy	exp	rzg.
1	31				C .	24	2					15	FV	MX	RW	DT	UZ	JQ	AO	CH	NY	k t l	acw	zsi	05%
1	3.	rO	ТО	rs	25	20	02	КМ	AX	PZ	00	DI	AT	CV	10	ER	0S.	LW	P2	FN	BH	ioc	acn	OVW	bvw
8	2				14		03	DI	CN	RR	PV	CR	PV	AT	DK	OT	NO	EU	вх	LP	0J	1 rb	cld	ude	rzh
9	28	11	m	v	00	30	10	1.0	80	ue	1114	DY	TN	BV	OR	AM	LO	PP	HT	EX	UW	woj	fbh	vet	uis
8	27	III	1	IV	11	03	0/	DT	50	na	0%	W7	41.	RT	KO	co	EI	BJ	DU	FS	HP	xle	gbo	uev	rxm
6	26	1	IV	4								OP	PV	AD	IT	PK	HJ	LZ	NS	EQ	CW	ouc	uhq	uew	uit
9	25	IV	m	r	in		r		-			TY	15	OX	KV.	JM	DR	нх	GL	C2.	NU	kp1	rw1	vci	tlq
8	24	v	1			Ę	5					iov	FR	AK	EO	DH	CJ	MZ	SX	ON	LT	ebn	rwm	udf	tlo
9	23	11	11									P1	23	TN	RY	LV	AY	ou	BO	WZ	CN	19¢	acx	mwe	wvc
0	22	11	14	v	01	69	21	10	AS	DV	OL	PIL	HI.	FY	05	02	DM	AW	CE	TV	NX	Jpw	del	mwf	wvf
91	21	1	v	11	13	05	19	PT	OX	EZ	CH	I NO		07.	AU	BY	sv	JL	ox	BE	TW	bpt	cef	nvo	ysh
10	20	111	1V	v	24	2		_ 1	Π.					FH	WY	DL	CM	AE	72	15	GI	idf	fpx	JWE	tig
49	19	V	III	1	17	1	r	-1	16	26	Т	O	r i	TV	40	XX	FX	NT	PS	LU	BD	153	*9*	vej	rxn
49	18	IV	n	· · ·	15	1.								LS	EM.	ov	OY	QX	AP	JP	BU	mae	hzi '	sog	ysi.
49	17	1 . 1 -	IV	11	21	10	12					НМ	10	DI	NR	BY	XZ	05	PU	FQ	CT	tdp	dhb	fkb	uiv
49	16	V.	11	m	00	10	07	1.5				DS	HY	MR	0W	LX	AJ	BQ	co	IP	NT	ldw	hzj	soh	wvg
49	15	11		1	101	05	01	1				i GM									v	imz	noa	tjv	xtk
49	14	1. 1V	1		15	10	03	VI	вт	MV	но	LY	n	1.		m l	h		יו ב	-	х	zgr	dgz	sjo	ryg
49	13	-1		II	10	10	07	PW	EL	DO	KN	MU	P		U ;					U	W	zdy	rkf	tjw	xti
9.99	12	- · ·	1	1.	102	26	15	RZ	00	CP	SX	KN									v	203	rjy	501	wvn
949	11	1 11	IV	111	1 22	20	01					LR	IK	MS	QU	Н₩	PT	00	VX	FZ	EN	Irc	zbx	vbm	TXO
999	1.10		v	111	16	00	63					' QY	BS	LN	KT	AP	IU	DW	но	RV	JZ	edj	eyr	v6y	CIN
940	12		· · · ·	· · w	1 13	1 10	25	-				FI	NQ	SY	CU	BZ	HA	EL	TX	DO	KP	У			
999	1	- 1	II IV	11	00	0	22					. UX	12	HN	BK	QQ	CP	FT	JY	MW	AR	11		SI	ГІО
949			14	W	1 11	15	1.14					. DQ	GU	BW	NP	HK	A2	CI	PO	JX	vY	11		-	
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245			11		0	2 2	05	QT	W2	K K	GN	. AC	BL	02	EK	QX	OP	SU	DH	JM	TX	150	209	v Cy	wak
041			1	11	119	2 1	1 00	BF	NE	DX	CS	· KR	MP	CN	BF	EH	DZ	IW	AV	OJ	LO	Iap	bwo	ivf	rtd
041			v	1	110	5 1	4 03					BN	HU	EO	PY	KQ	CP	os	JW	AI	vZ	aqa	ouy.	ain.	with
031		<[17			1.17			10				-		312	CV	0V	NO	AP	UY	SW	30	1 881	cui	014	

 $5 \cdot 4 \cdot 3 \cdot 26^3 \cdot 24!/(12!2^{12}) \cdot 26!/(10!6!2^{10}) \cdot 26^3 \simeq 150$ undecillion 789 decillion 931 nonillion 331 octillion 314 septillion 839 sextillion

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01	21				1	26	62					15	EV	MX	RW	DT	UZ	JQ	٨0	CH	NY	k t l	acw	zsi	20	
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8	23				00	02	07	1.0	50	HS	IIV	DY	IN	BV	OR	AM	LO	PP	HT	EX	UW	woj	fbh	vet	uis	
9	27	m	1	IV	11	03			D.4		0.	V2	AL.	RT	KO	co	E1	BJ	DU	FS	HP	xle	gbo	uev	rxm	
8	26	1	IV .									OR	PV	AD	IT	PK	HJ	LZ	NS	EQ	CW	ouc	uhq	uew	uit	
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8	24	v	1			E						iov	FR	AK	EO	DH	CJ	MZ	SX	ON	LT	ebn	rwm	udf	tlo	
9	23	14	II		1.01					nu		PJ	ES	IM	RX	LV	AY	00	BO	WZ	CN	jąc	acx	mwe	wvc	
10	22	11	IV	v	101	05	10	10	AD	Dv	0 D	RU	HL	FY	05	02	DM	AW	CΕ	TV	NX	Jpw	del	mwf	wvf	
10	21	1			13	05	19	PT	ox	ΕZ	CH	1		QZ	AU	RY	sv	JL	0 X	BE	TW	jqd	cef	nvo	ysh	
19	20	m	11	, Y	17	2		_ f	Ξ.	~ ~		~.		FH	WY	DL	CM	AE	72	15	GI	idf	fpx	JWE	tig_	
49	19				15	1	r	- 1	It	20	ЛL.	UI	1	IV	AQ	XW	FX	MT	PS	LU	BD	1 5 8	≋рж	vej	rxn.	
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46	1.	·	11		08.	16	13					НМ	JO	DI	NR	BY	XZ	05	PU	FQ	CT	tdp	dhb	IKD	UIV	
19	10	, in	IV	1	01	03	07					DS	HY	MR	0.8	ΓX	٨J	BQ	CO	IP	NT	ldw	hzj	son	wvg.	
40	12	111		v	15	11	05	1.1	DT	WV	нп	I GM									V.	imz	noa	CJ V	X CK	
40	112	1	in	ii.	13	20	03	1		Da	N.M	LY	n				n (n:	יר	1	X	zgr	dgz	810	1.9%	
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40	11	1 11	IV	111	1 02	26	15	RZ	00	CP	21	KN			_						V.	202	159	whm	TTO	
140	110	III	v	11	23	21	01					LR	IK	MS	QU	H¥	PT	00	VX	FZ	EN T2	irc	LUX	vbv	tih	
149	1.0	v	1	111	16	04	63	1				QY	BS	LN	KT	AP	10	DW	no	RV DO	VP	eej	0,1	,	-	
349	8	1 TV	Ш	v	13	19	25	-	1111		100	FI	NQ	SY	CU	82	HA	5L	11	NW	AR		20		Lio	1
849	17	11	1V	11	09	03	22					. UX	12	HN	BK	00	UP .2	CT	PO	TY	VY	1	JU	51	LIU	J
649	16	in	I	v	11	18	14	1		- 111	не	; DQ	GU	BW	NP	nK	AL	ue	PY	NW	FY	1				
649	5	V	11	IV	23	02	25	1 10			01	MV.	CL	OK	00	DI	01	511	DH	IM	TX	150	zby	vcy	ujb	
845	4	1 11	1V	1	04	21	05	QT	W 2	KV.	0.	. AC	BL	OZ	EK BP	CH.	D7	TW	AV	GJ	LO	lap	owd	iwu	wak	
849	3	V	1	11	19	11	00	BF	NH	DX	. 02	KR	MP	FO	PY	KO	CP	os	JW	AL	V2	aqd	bdy	iyf	xtd.	
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 $5 \cdot 4 \cdot 3 \cdot 26^3 \cdot 24!/(12!2^{12}) \cdot 26!/(10!6!2^{10}) \cdot 26^3 \simeq 150$ undecillion 789 decillion 931 nonillion 331 octillion 314 septillion 839 sextillion 42 quintillion

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R.	3.	r O	ГО	rs	25	20	02	КИ	AX	PZ	00	DI	AT	CV	10	ER	0S.	LW	P2	FN	BH	ioc	acn	OVW	bvw	
8	2			_	14		03	DI	CN	RR	PV	CR	PV	AT	DK	OT	NO	EU	вх	LP	OJ	1 rb	cld	ude	rzh	
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16	26	1	IV .									OP	PV	AD	IT	PK	HJ	LZ	NS	EQ	CW	ouc	uhq	uew	uit	
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49	24	v	1			Ę	5	1.2				iov	FR	AK	EO	DH	CJ	MZ	SX	ON	LT	ebn	rwm	udf	tlo	
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40	22	11	IV	V	01	09	21	10	AS	DV	OL	PII	HI.	FY	05	02	DM	AW	CE	TV	NX	Jpw	del	mwf	wvf	
40	21	1	v		13	05	19	PT	OX	E2	CH	1 NO		07.	AU	BY	sv	JL	ox	BE	TW	jqd	cef	nvo	ysh	
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49	19	V	111	1	17	3	r	ет	16	26	Т	OI	r ;	TV	A0	XX	FX	MT	PS	LU	BD	158	"bw	vej	rxn.	
49	18	IV	11	v	15			<u> </u>		~~		<u> </u>		LS	EM.	ov	OY	QX	AP	JP	BU	mae	hzi '	sog	ysi.	
149	17	1	IV	12	21	10	00						10	DT	NR	BY	X.2	05	PU	FQ	CT	tdp	dhb	fkb	uiv	
149	16	v	11	III	08	16	13					DS	HY	MR	0W	LX	AJ	BQ	co	IP	NT	1 dw	hzj	soh	wvg.	
349	15	11	IV .	1	01	03	0/					iev									v	imz	noa	tjv	xtk	
349	14	11	1	v	15	11	05	IA	BT	MA	HU	LY	-			- C	~		2	-	х	zgr	dgz	gjo	ryg	12
849	13	- 1		11	13	20	03	FW	EL	DO	KN	MU	ų		и ;					U	W	zdy	rkf	tjw	xti	
349	12	. V	15	IV	18	26	10	RZ	00	CP	SX	KN									v	202	rjy	soi	wvh	
849	11	1 11	IV	III	1 02	20	15					LB	IK	MS	QU	HW	PT	00	VX	FZ	EN	lrc	zbx	vbm	TXO	
849	.10	III	v	11	23	21	0					QY	BS	LN	KT	AP	IU	DW	но	RV	JZ	edj	eyr	vby	tih	
649	19	V			. 10	10	05	-				FI	NQ	SY	CU	B2	AH	EL	TX	DO	KP	У				
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 $5 \cdot 4 \cdot 3 \cdot 26^3 \cdot 24!/(12!2^{12}) \cdot 26!/(10!6!2^{10}) \cdot 26^3 \simeq 150$ undecillion 789 decillion 931 nonillion 331 octillion 314 septillion 839 sextillion 42 quintillion 76 quadrillion

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R.	3.	r O	ГО	rs	25	20	02	КИ	AX	PZ	00	DI	AT	CV	10	ER	0S.	LW	P2	FN	BH	ioc	acn	OVW	bvw	
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16	26	1	IV .									OP	PV	AD	IT	PK	HJ	LZ	NS	EQ	CW	ouc	uhq	uew	uit	
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49	24	v	1			Ę	5	1.2				iov	FR	AK	EO	DH	CJ	MZ	SX	ON	LT	ebn	rwm	udf	tlo	
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40	22	11	IV	V	01	09	21	10	AS	DV	OL	PI	HI.	FY	05	02	DM	AW	CE	TV	NX	Jpw	del	mwf	wvf	
40	21	1	v		13	05	19	PT	OX	E2	CH	1 NO		07.	AU	BY	sv	JL	ox	BE	TW	jqd	cef	nvo	ysh	
49	20	111	1V	v	24	9		_ (1					FH	WY	DL	CM	AE	72	15	GI	idf	fpx	JWE	tig	
49	19	V	111	1	17	3	r	ет	16	26	Т	OI	r ;	TV	A0	XX	FX	MT	PS	LU	BD	158	"bw	vej	rxn.	
49	18	IV	11	v	15			<u> </u>		~~		<u> </u>		LS	EM.	ov	OY	QX	AP	JP	BU	mae	hzi '	sog	ysi.	
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349	15	11	IV .	1	01	03	0/					iev									v	imz	noa	tjv	xtk	
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849	13	- 1		11	13	20	03	FW	EL	DO	KN	MU	ų		43					U	W	zdy	rkf	tjw	xti	
349	12	. V	15	IV	18	26	10	RZ	00	CP	SX	KN									v	202	rjy	soi	wvh	
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049	4	- I W	IV		110	1	1 0	BF	NE	DX	CS	· KR	MP	CN	BF	EH	DZ	IW	AV	0J	LO	lap	owd	190	wid.	
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A random permutation of the alphabet:



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A random permutation of the alphabet:



Cycle structure: 6-2-2-3-4-7-2

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An enigma permutation of the alphabet:



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An enigma permutation of the alphabet:



Don't use just one daily key!

- If you use the same daily key on all messages that day, then one could try frequency analysis on all the first characters of all the messages. Then frequency analysis on all second characters, etc.
- 2. So, choose a random message key (rotor start positions, e.g. BLA) and send that using the daily key.
- 3. Then send the message in the message key.
- 4. BUT: radio is noisy, so send it twice (send BLABLA encrypted with daily key).

Message key: BLA Encrypted message key (using daily key):

$$\begin{vmatrix} \mathbf{B} & \mathbf{L} & \mathbf{A} & \mathbf{B} & \mathbf{L} & \mathbf{A} \\ \sigma_1 & \sigma_2 & \sigma_3 & \sigma_4 & \sigma_5 & \sigma_6 \\ \mathbf{A} & \mathbf{G} & \mathbf{Q} & \mathbf{W} & \mathbf{T} & \mathbf{E} \end{vmatrix}$$

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Learned information about $\sigma_4 \circ \sigma_1$:

 $A \to W$

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Message key: BLA Encrypted message key (using daily key):

Learned information about $\sigma_4 \circ \sigma_1$:

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1. Collect these bits of info to discern cycle structure of $\sigma_4 \circ \sigma_1$.

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- This depends only on daily key rotor positions (not plugboard).

Message key: BLA Encrypted message key (using daily key):

Learned information about $\sigma_4 \circ \sigma_1$:

$$A \to W$$

- 1. Collect these bits of info to discern cycle structure of $\sigma_4 \circ \sigma_1$.
- This depends only on daily key rotor positions (not plugboard).
- 3. Use a lookup table to determine rotor positions!



Bletchley Park Bombe replica (Antoine Taveneaux) , Carton and Carton Content of the second se

Substitution cipher. A cipher that acts on letters of the plaintext one-by-one according to a permutation of the alphabet.

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Examples:

- 1. Caesar cipher
- 2. Affine cipher
- 3. Newspaper Cryptogram puzzles

Classical cryptography terminology

Transposition cipher. A cipher that acts on the plaintext by reordering its letters.

Examples:

- 1. Second half of ADFGXV cipher
- 2. RailFence Cipher

HELPIMTRAPPEDBEHINDAFENCE -H-I-A-D-I-F-E-E--E-P-M-R-P-E-B-H-N-A-E-C -L-T-P-E-D-N-

HIADIFEEPMRPEBHNAECLTPEDN

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Classical cryptography terminology

Fractionating cipher. A cipher that replaces each plaintext character with several ciphertext characters.

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Examples:

1. Polybius square (first half of ADFGXV cipher)

Polyalphabetic cipher. A substitution cipher that uses a changing substitution key for each character.

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Examples:

- 1. Vigenere cipher.
- 2. Enigma machine.

Classical cryptography terminology

Block cipher. A cipher that encrypts block-by-block instead of character-by-character.

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Examples:

1. Hill cipher.

Diffusion. A property of a cipher, namely that changing one character of plaintext results in many characters of ciphertext changing, and vice versa.

The idea: Prevents frequency analysis, because statistics of the plaintext "diffuse" to statistics of the ciphertext.

Examples:

1. Block ciphers satisfy diffusion (more if bigger blocks).

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2. Vigenere cipher does not satisfy diffusion.

Classical cryptography terminology

Confusion. A property of a cipher, namely that changing they key only slightly will result in the ciphertext changing a lot.

The idea: Prevents cryptanalysing the key one piece at a time, since each character of ciphertext depends on many parts of the key.

Examples:

- 1. Enigma has a fair bit of confusion. (A different rotor position on one rotor for example will change everything.)
- 2. Vigenere cipher does not satisfy confusion. (Each ciphertext character depends on only one character of the key.)

Advent of Computers: DES (Data Encryption Standard)



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1. Block cipher

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- 1. Block cipher
- 2. Runs on binary bits (natural for a computer)

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- 1. Block cipher
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- 3. Components: permuting digits, expansion, XOR, S-boxes
 - Very classical cipher ideas
 - Very efficient to implement on computers

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5. Cryptanalysis: Exhaustive search, differential cryptanalysis, linear cryptanalysis

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- 5. Cryptanalysis: Exhaustive search, differential cryptanalysis, linear cryptanalysis
- 6. Symmetric-key cryptography; used in tandem with public-key cryptography

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send a DES key with public key cryptography then use DES

- 1. Block cipher
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- send a DES key with public key cryptography then use DES
- 7. Used 1975-2000
 - ▶ in 1999: broken in 22 hours, 15 minutes (distributed)
 - now you can buy a fancy computer and do it in 15 days

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 - Triple DES is an alternative where you do DES three times.

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- 10. Mathematically speaking, the culmination of classical cryptography and the beginning of modern academic cryptography.

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