Cambridge Assessment International Education
Cambridge International Advanced Level

FURTHER MATHEMATICS **9231/22**

Paper 2 **May/June 2019**

MARK SCHEME

Maximum Mark: 100

Published

This mark scheme is published as an aid to teachers and candidates, to indicate the requirements of the examination. It shows the basis on which Examiners were instructed to award marks. It does not indicate the details of the discussions that took place at an Examiners' meeting before marking began, which would have considered the acceptability of alternative answers.

Mark schemes should be read in conjunction with the question paper and the Principal Examiner Report for Teachers.

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Generic Marking Principles

These general marking principles must be applied by all examiners when marking candidate answers. They should be applied alongside the specific content of the mark scheme or generic level descriptors for a question. Each question paper and mark scheme will also comply with these marking principles.

GENERIC MARKING PRINCIPLE 1: Marks must be awarded in line with: • the specific content of the mark scheme or the generic level descriptors for the question • the specific skills defined in the mark scheme or in the generic level descriptors for the question • the standard of response required by a candidate as exemplified by the standardisation scripts.
GENERIC MARKING PRINCIPLE 2: Marks awarded are always **whole marks** (not half marks, or other fractions).
GENERIC MARKING PRINCIPLE 3: Marks must be awarded **positively**: • marks are awarded for correct/valid answers, as defined in the mark scheme. However, credit is given for valid answers which go beyond the scope of the syllabus and mark scheme, referring to your Team Leader as appropriate • marks are awarded when candidates clearly demonstrate what they know and can do • marks are not deducted for errors • marks are not deducted for omissions • answers should only be judged on the quality of spelling, punctuation and grammar when these features are specifically assessed by the question as indicated by the mark scheme. The meaning, however, should be unambiguous.
GENERIC MARKING PRINCIPLE 4: Rules must be applied consistently e.g. in situations where candidates have not followed instructions or in the application of generic level descriptors.

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GENERIC MARKING PRINCIPLE 5: Marks should be awarded using the full range of marks defined in the mark scheme for the question (however; the use of the full mark range may be limited according to the quality of the candidate responses seen).
GENERIC MARKING PRINCIPLE 6: Marks awarded are based solely on the requirements as defined in the mark scheme. Marks should not be awarded with grade thresholds or grade descriptors in mind.

Mark Scheme Notes

The following notes are intended to aid interpretation of mark schemes in general, but individual mark schemes may include marks awarded for specific reasons outside the scope of these notes.

Types of mark

M Method mark, awarded for a valid method applied to the problem. Method marks are not lost for numerical errors, algebraic slips or errors in units. However, it is not usually sufficient for a candidate just to indicate an intention of using some method or just to quote a formula; the formula or idea must be applied to the specific problem in hand, e.g. by substituting the relevant quantities into the formula. Correct application of a formula without the formula being quoted obviously earns the M mark and in some cases an M mark can be implied from a correct answer.

A Accuracy mark, awarded for a correct answer or intermediate step correctly obtained. Accuracy marks cannot be given unless the associated method mark is earned (or implied).

B Mark for a correct result or statement independent of method marks.

Abbreviations

AEF/OE Any Equivalent Form (of answer is equally acceptable) / Or Equivalent

AG Answer Given on the question paper (so extra checking is needed to ensure that the detailed working leading to the result is valid)

CAO Correct Answer Only (emphasising that no “follow through” from a previous error is allowed)

CWO Correct Working Only – often written by a ‘fortuitous’ answer

ISW Ignore Subsequent Working

SOI Seen or implied

SC Special Case (detailing the mark to be given for a specific wrong solution, or a case where some standard marking practice is to be varied in the light of a particular circumstance)

Question	Answer	Marks	Guidance
1(i)	$a_R = 2\,(\mathrm{d}\theta/\mathrm{d}t)^2 = 2\,(2\sin 2t)^2 = 2\,(2\sin \pi/3)^2$	**M1**	Verify radial acceleration a_R at $t = \pi/6$ from $r\omega^2$
	$= 2\,(\sqrt{3})^2 = 6$ [m s^{-2}] AG	**A1**	
		2	
1(ii)	$a_T = 2\,\mathrm{d}^2\theta/\mathrm{d}t^2 = 2\,(4\cos 2t) = 2\,(4\cos \pi/3)$	**M1**	Find transverse acceleration a_T at $t = \pi/6$ by differentiation
	$= 4$ [m s^{-2}]	**A1**	
		2	

Question	Answer	Marks	Guidance
2(i)	$v_B = 2v_A$, $v_B^2 = 4\ v_A^2$, $\omega^2 (a^2 - 1^2) = 4\omega^2 (a^2 - 3{\cdot}5^2)$	**M1**	Find amplitude a: allow M1 for $v_A = 2\ v_B$
	$3\ a^2 = 48$, $a = [\pm]\ 4$ [m]	**A1**	
	$1 = a\omega^2$, $\omega = 1/\sqrt{a}$ [= ½]	**B1**	Find ω from given maximum acceleration
	$v_O = a\omega = \sqrt{a} = 2$ [m s^{-1}]	**B1**	Find speed v_O at O
		4	
2(ii)	$\omega\ t_{AB} = \sin^{-1}(3.5/a) + \sin^{-1}(1/a)$ $= \sin^{-1} 0{\cdot}875 + \sin^{-1} 0{\cdot}25$	**M1 A1**	Find equation (AEF) for $\omega\ t_{AB}$, combining t_A and t_B, using for example $x = a \sin \omega t$ allow sign errors for the M1
	$= 1{\cdot}065 + 0{\cdot}253$ (*or* $t_{AB} = 2{\cdot}131 + 0{\cdot}505$)	**A1**	*or* $x = a \cos \omega t$
	$t_{AB} = 2 \times 1{\cdot}318 = 2{\cdot}64$ [s]	**A1**	Hence find t_{AB}
	Alternative method for question 2(ii)		
	$\omega\ t_{AB} = \cos^{-1}(-1/a) - \cos^{-1}(3.5/a)$ $= \cos^{-1}(-0{\cdot}25) - \cos^{-1} 0{\cdot}875$ *or* $\pi - \cos^{-1} 0{\cdot}25 - \cos^{-1} 0{\cdot}875$ (AEF)	**M1 A1**	*or* $x = a \cos \omega t$
	$= 1{\cdot}823 - 0{\cdot}505$ (*or* $t_{AB} = 3{\cdot}647 - 1{\cdot}011$)	**A1**	
	$t_{AB} = 2 \times 1{\cdot}318 = 2{\cdot}64$ [s]	**A1**	Hence find t_{AB}
		4	

Question	Answer	Marks	Guidance
3(i)	$2mv_A + 4mv_B = 4mu - 4mu$ $[v_A + 2v_B = 0]$ (AEF)	**M1**	Use conservation of momentum for A and B (m may be omitted)
	$v_B - v_A = e\,(2u + u)$ $[v_B - v_A = 3eu]$	**M1**	Use Newton's restitution law with consistent LHS signs
	$v_A = -2eu$ *and* $v_B = eu$	**A1**	Combine to find v_A and v_B (A0 if directions unclear)
		3	
3(ii)	$[4mv_B'] + mv_C = 4mv_B - (4/3)\,mu$ (AEF)	**M1**	Use conservation of momentum for B & C (m may be omitted)
	$v_C\,[-v_B'] = e\,(v_B + 4u/3)$	**M1**	Use Newton's restitution law
	$4v_B - (4/3)\,u = ev_B + 4eu/3,\ 4e - 4/3 = e^2 + 4e/3$	**M1**	Combine to find quadratic equation for e using $v_B' = 0$
	$3e^2 - 8e + 4 = 0,\quad e = 2/3\quad [v_C = 4u/3]$	**A1**	Find value of e, (implicitly) rejecting $e = 2$
		4	

Question	Answer	Marks	Guidance
3(iii)	*For A: Loss* = ½ 2m(2u)^2 - ½ 2m(4/3u)^2 = (20/9) mu^2 *For B: Loss* = ½ 4m u^2 = ½ mu^2 For C: Loss = 0	**M1**	v_A = – (4/3) u , [v_B = (2/3) u], v_C = (4/3) u One correct
		M1	Other two correct
	$E_{initial} - E_{final}$ *or* $L_1 + L_2$ = (38/9) mu^2	**A1**	Hence find loss in KE
	Alternative method for question 3(iii)		
	$E_{initial}$ = ½ 2m(2u)^2 + ½ 4mu^2 + ½ m(4u/3)^2 = 4mu^2 + 2mu^2 + (8/9) mu^2 = (62/9) mu^2	**M1**	Find initial KE of 3 particles in terms of m and u
	E_{final} = ½ 2mv_A^2 [+ ½ 4$mv_B'^{\,2}$] + ½ $mv_C^{\,2}$ = (16/9) mu^2 + (8/9) mu^2 = (24/9) mu^2	**M1**	Find final KE of 3 particles in terms of m and u
	$E_{initial} - E_{final}$ *or* $L_1 + L_2$ = (38/9) mu^2	**A1**	Hence find loss in KE
	Alternative method for question 3(iii)		
	L_1 = ½ 2m(2u)^2 + ½ 4mu^2 – ½ 2mv_A^2 – ½ 4$mv_B^{\,2}$ = 4mu^2 + 2mu^2 – (16/9) mu^2 – (8/9) mu^2 = (30/9) mu^2	**M1**	Find losses in KE in both collisions in terms of m and u
	L_2 = ½ 4$mv_B^{\,2}$ + ½ m(4u/3)^2 – [½ 4$mv_B'^{\,2}$] – ½ $mv_C^{\,2}$ = (8/9) mu^2 + (8/9) mu^2 – (8/9) mu^2 = (8/9) mu^2	**M1**	
	$E_{initial} - E_{final}$ *or* $L_1 + L_2$ = (38/9) mu^2	**A1**	Hence find loss in KE
		3	

Question	Answer	Marks	Guidance
4	A: $T \times 5a/2 \sin(\pi - 2\theta) - W \times 2a \sin\theta = 0$ C: $F_A \times 5a/2 \sin\theta - R_A \times 5a/2 \cos\theta - W \times ½\, a \sin\theta = 0$ B: $F_A \times 4a \sin\theta - R_A \times 4a \cos\theta - W \times 2a \sin\theta$ $+ T \times 3a/2 \sin(\pi - 2\theta) = 0$ G: $F_A \times 2a \sin\theta - R_A \times 2a \cos\theta - T \times ½\, a \sin(\pi - 2\theta) = 0$ (G is mid-point of AB) D: $R_A \times 5a \cos\theta - W \times 2a \sin\theta = 0$	M1 A1	Take moments for rod about one chosen point [$\sin\theta = 2/\sqrt{5}$, $\cos\theta = 1/\sqrt{5}$, $\sin(\pi - 2\theta) = \sin 2\theta = 4/5$]
	$R_A = T \sin\theta$ $F_A = W - T\cos\theta$	B1	Find two more independent equations
		B1	e.g. resolution of forces on rod (a second moment equation may be used)
	$F_A = \mu R_A$	B1	Relate F_A and R_A (may be implied)
	$T = (2W \sin\theta) / (5/2 \sin 2\theta) = 2W / (5\cos\theta)$	M1	Find T by any method (e.g. from moments about A)
	$= 2W/\sqrt{5}$ *or* $(2\sqrt{5}/5)\, W$ *or* $0{\cdot}894\, W$	A1	
	$F_A = (3/5)\, W$ *and* $R_A = (4/5)\, W$ $\mu = ¾$ *or* $0{\cdot}75$	M1 A1	Find or imply F_A *and* R_A by any method (e.g. from resolutions) and hence μ
		A1	
		10	

Question	Answer	Marks	Guidance
5(i)	$I_{rod} = ⅓\ kMa^2$	B1	Find or state MI of rod AB about axis L
	$I_{sphere} = ⅔\ kM(2a)^2 + kM(3a)^2$ [= (35k/3) Ma^2]	M1 A1	M1 for one term correct, A1 for both terms correct
	$I_{ring} = ½ \times Ma^2 + M(2a)^2$ [= (9/2) Ma^2]	M1 A1	M1 for one term correct, A1 for both terms correct
	$I = (k/3 + 35k/3 + 9/2)\ Ma^2 = (3/2)(8k + 3)\ Ma^2$ AG	A1	MI of object about axis L
		6	
5(ii)	[–] $I\ d^2\theta/dt^2 = -kMg \times 3a \sin\theta + Mg \times 2a \sin\theta$ [= – (3k – 2) $Mga \sin\theta$]	M1 A1	Use equation of circular motion to find $d^2\theta/dt^2$ where θ is angle of rod with vertical
	$d^2\theta/dt^2 = -\{2g(3k - 2) / 3a(8k + 3)\}\ \theta$ (AEF)	M1	Approximate $\sin\theta$ by θ to give standard form of SHM equation (M0 if wrong sign or $\cos\theta \approx \theta$ used)
	SHM if $3k - 2 > 0$, $k > 2/3$	M1 A1	Find possible values of k
	$T = 2\pi \sqrt{\{3a(8k + 3) / 2g(3k - 2)\}}$ *or* $\pi \sqrt{\{6a(8k + 3) / g(3k - 2)\}}$	A1	Find period T
		6	

Question	Answer	Marks	Guidance
6(i)	Mean = 3	**B1**	State mean of X
		1	
6(ii)	$P(X = 6) = q^5 p$ with $p = 1/3$, $q = 2/3$ (AEF) $= 32/729$ *or* 0·0439	**B1**	Find probability of score of 3 or 4 on exactly 6 throws
		1	
6(iii)	$P(X > 4) = q^4 = 16/81$ *or* 0·1975 *or* 0·198	**M1 A1**	Find probability of score of 3 or 4 on more than 4 throws
		2	
6(iv)	$1 - q^{n-1} < 0{\cdot}95$ (AEF)	**M1**	Formulate condition for n ($1 - q^n$ is M0)
	$0{\cdot}05 < (2/3)^{n-1}$, $n - 1 < \log 0{\cdot}05 / \log 2/3$	**M1**	Set $q = 2/3$, rearrange and take logs (any base) to give bound
	$n - 1 < 7{\cdot}39$, $n_{\max} = 8$	**A1**	Find $n_{\max}$ (> or = can earn M1 M1 A0, max 2/3)
		3	

Question	Answer	Marks	Guidance
7(i)	$F(x) = \int f(x)\,dx = -3/(4x) + x/4$ [+ c]	**M1**	Find or state distribution function $F(x)$ for $1 \leqslant x \leqslant 3$
	$= -3/(4x) + x/4 + ½$ *or* $¼\,(-3/x + x + 2)$	**A1**	using $F(1) = 0$ or $F(3) = 1$ to find c if necessary
	$F(x) = 0$ ($x <$ *or* $\leqslant 1$), $F(x) = 1$ ($x >$ *or* $\geqslant 3$)	**A1**	State $F(x)$ for other values of x
		3	
7(ii)	$\int_1^Q f(x)\,dx = -3/4Q + Q/4 + ½ = ¼$ [*or* ¾] (AEF)	**M1**	Formulate equation for either quartile value Q
	$Q^2 +$ [*or* $-$] $Q - 3 = 0$	**A1**	
	$Q_1 = ½\,(-1 + \sqrt{13})$, $Q_3 = ½\,(1 + \sqrt{13})$	**A1 A1**	Find lower quartile Q_1 and upper quartile Q_3
	$Q_3 - Q_1 = 1$	**A1**	Find interquartile range
		5	

Question	Answer	Marks	Guidance
8	H_0: $\mu_b - \mu_e = 0{\cdot}05$, H_1: $\mu_b - \mu_e > 0{\cdot}05$ (AEF)	**B1**	State both hypotheses (B0 for $\bar{x}$ …)
	d_i: 0·10 0·07 0·03 0·03 0·21 0·19 (or in sec)	**M1**	Consider differences d_i from e.g. $x_b - y_e$
	$\bar{d} = 0{\cdot}63 / 6 = 0{\cdot}105$ (or 6·3 sec)	**B1**	Find sample mean
	$s^2 = (0{\cdot}0969 - 0{\cdot}63^2/6) / 5$ [= 123/20 000 *or* 0·00615 *or* $0{\cdot}0784^2$](or 22·14)	**M1**	Estimate population variance (allow biased here: [41/8000 *or* 0·005125 *or* $0{\cdot}0716^2$])
	$t_{5,\,0.9} = 1{\cdot}476$ (to 3 sf)	**B1**	State or use correct tabular t-value
	$t = (\bar{d} - 0{\cdot}05) / (s/\sqrt{6}) = 1{\cdot}72$	**M1 A1**	Find value of t (or compare $\bar{d} - 0{\cdot}05 = 0{\cdot}055$ with $(t_{5,\,0.9})s/\sqrt{6} = 0{\cdot}0473$)
	[Reject H_0:] Evidence for organiser's belief *or* times improve by more than 0·05 min (AEF)	**B1**	**FT** on both t-values Consistent conclusion
			SC Wrong type of hypothesis test can earn only B1 for hypotheses B1FT for conclusion (max 2/8)
		8	

Question	Answer	Marks	Guidance
9 (i)	$E_3 = (3/16) \int_{1.6}^{2.4} (4 - x)^{1/2}\, dx$ $= (3/16) [- (2/3) (4 - x)^{3/2}]_{1.6}^{2.4}$	**M1**	State or imply expression for required expected value E_3 of X
	$= (2{\cdot}4^{3/2} - 1{\cdot}6^{3/2}) / 8 = 1{\cdot}694/8$ *or* $0{\cdot}2118$	**A1**	Find expected value E_3 (may be implied in finding 50 E_3) (M1 A1 requires adequate explicit working)
	$50\, E_3 = 10{\cdot}59$ AG	**A1**	Hence verify corresponding expected frequency
		3	
9(ii)	H_0: Distribution fits data (AEF)	**B1**	State (at least) null hypothesis in full
	O_i 18 16 8 $\underline{8}$ E_i: 14·22 12·54 10·59 $\underline{12{\cdot}65}$ X^2 = 1·005 + 0·955 + 0·633 + 1·709 = 4·30	**M1**	Combine values consistent with all exp. values ≥ 5
		M1 A1	Find value of X^2 from $\Sigma\, (E_i - O_i)^2 / E_i$ [or $\Sigma\, O_i^2/E_i - n$]
	No. n of cells: 5 $\underline{4}$ 3 $\chi_{n\text{-}1,\, 0.95}{}^2$: 9·488 $\underline{7{\cdot}815}$ 5·991 (to 3 s.f.)	**B1**	**FT** on number, n, of cells used to find X^2 State or use consistent tabular value $\chi_{n\text{-}1,\, 0.95}{}^2$
	Accept H_0 if X^2 < tabular value (AEF)	**M1**	State or imply valid method for conclusion
	4·30 [± 0·01] < 7·81[5] so distribution fits [data] *or* distribution is a suitable model (AEF)	**A1**	Conclusion (requires both values approx. correct)
		7	

Question	Answer	Marks	Guidance
10(i)	$\Sigma x = 25$, $\Sigma y = 25 + q$, $\Sigma xy = 135 + 4q$, $\Sigma x^2 = 141$, $\Sigma y^2 = 159 + q^2$	**B1**	Find required values
	$S_{xy} = 135 + 4q - 25(25 + q)/5 = [10 - q]$ (AEF) $[S_{xx} = 141 - 25^2/5 = 16]$ $S_{yy} = (159 + q^2) - (25 + q)^2/5$ $[= 34 - 10q + 4q^2/5]$	**M1 A1**	(S_{xy}, S_{xx}, S_{yy} may be scaled by the same constant)
	$40 - 4q = 170 - 50q + 4q^2$, $2q^2 - 23q + 65 = 0$ $(2q - 13)(q - 5) = 0$, $q = 5$	**M1 A1**	Equate gradient 5/4 in line of x on y to S_{xy} / S_{yy} and solve quadratic to find integer value of q
		5	
10(ii)	$c = 25/5 - (5/4)(25 + q)/5 = -(5 + q)/4$	**M1 A1**	Find c from $\bar{x} - (5/4)\bar{y}$
	$= -5/2$ *or* $-2{\cdot}5$	**A1**	
		3	
10(iii)	$r = S_{xy} / \sqrt{(S_{xx} S_{yy})} = 5 / \sqrt{(16 \times 4)}$	**M1 A1**	Find correlation coefficient r
	$= 5/8$ or $0{\cdot}625$	**A1**	
		3	

Question	Answer	Marks	Guidance
11E(i)	$\frac{1}{2}mu_P^2 = \frac{1}{2}m\,(21ag/2) + mga$ $[u_P^2 = (25/2)\,ag]$	**M1 A1**	u_P is speed of P at lowest point, v_Q is speed of Q immediately after collision. Apply conservation of energy at lowest point (A0 if no m)
	$\frac{1}{2}\,4mv_Q^2 = 4mag$	**M1**	Find speed v_Q at lowest point by conservation of energy (A0 if no m)
	$v_Q = \sqrt{(2ag)}$ *or* $1{\cdot}41\sqrt{(ag)}$ *or* $4{\cdot}47\sqrt{a}$	**A1**	
	$mu_P = [\pm]\,mv_P + 4mv_Q$	**M1**	Find v_P using conservation of momentum (m may be omitted)
	$v_P = [\pm]\,(-5/\sqrt{2} + 4\sqrt{2})\,\sqrt{(ag)}$	**A1**	
	$\lvert v_P \rvert = (3/\sqrt{2})\,\sqrt{(ag)}$ *or* $2{\cdot}12\,\sqrt{(ag)}$ *or* $0{\cdot}671\sqrt{a}$ (AEF)	**A1**	Hence find speed of P
		7	
11E(ii)	V_P is speed of P when it loses contact $\frac{1}{2}mV_P^2 = \frac{1}{2}mv_P^2 - mga\,(1 + \cos\alpha)$ $[V_P^2 = (9/2)ag - 2ga\,(1 + \cos\alpha) = (5/2 - 2\cos\alpha)\,ag]$	**M1 A1**	Apply conservation of energy at D (A0 if no m)
	$[R_D =]\ mV_P^2/a - mg\cos\alpha = 0$ $[V_P^2 = ag\cos\alpha]$	**M1 A1**	Apply $F = ma$ radially at D with reaction = 0
	$(5/2 - 2\cos\alpha)\,ag = ag\cos\alpha$, $\cos\alpha = 5/6$ *or* $0{\cdot}833$	**A1**	Combine to find $\cos\alpha$
		5	

Question	Answer	Marks	Guidance
11O(i)	$ts_A / \sqrt{8} = ½ (16·7 – 13·5)$ [$= 1·6$]	**M1**	Relate s_A to semi-width of confidence interval
	$t_{7,\, 0.975} = 2·365$ (to 3 s.f.)	**A1**	State or use correct tabular t value
	[$s_A = \sqrt{8} \times 1·6 / 2·365 = 1·9135$], $s_A{}^2 = 3·66$[16]	**A1**	Hence find unbiased estimate of A's population variance
		3	
11O(ii)	H_0: $\mu_A = \mu_B$, H_1: $\mu_A > \mu_B$ (AEF)	**B1**	State hypotheses (B0 for $\overline{x}$ …)
	[$\overline{x}_A = 15.1$], $\overline{x}_B = 85.2 / 6 = 14.2$	**B1**	Find sample mean for B
	$s_B{}^2 = (1221·06 – 85·2^2/6) / 5$ $= 561/250$ *or* $2·244$ *or* $1·498^2$ (all to 3 s.f.)	**M1**	Estimate or imply population variance for B (allow biased here: $1·87$ *or* $1·367^2$)
	$s^2 = (7\, s_A{}^2 + 5\, s_B{}^2) / 12 = 3·0709$ *or* $1·752^2$	**M1 A1**	Estimate (pooled) common variance ($s_B{}^2$ not needed explicitly)
	$t_{12,\, 0.95} = 1·782$	**B1**	State or use correct tabular t value
	[-] $t = (\overline{x}_A - \overline{x}_B) / (s \sqrt{(1/8 + 1/6)}) = 0·951$ $t < 1·78$ so [accept H_0]	**M1 A1**	Find value of t (or can compare $\overline{x}_A - \overline{x}_B = 0·9$ with $1·69$) Correct conclusion
	mean mass of B not less than mean mass of A (AEF)	**B1**	
		9	
			SC1: Implicitly taking $s_A{}^2$, $s_B{}^2$ as unequal population variances (may also earn first B1 B1 M1) $z = (\overline{x}_A - \overline{x}_B) / \sqrt{(s_A{}^2/8 + s_B{}^2/6)}$ $= 0·9 / \sqrt{(0·8317)} = 0·987$ $z < 1·645$ so
			DepSC1: mean mass of B not less than mean mass of A (AEF) Comparison with $z_{0.95}$ and conclusion (FT on z) (can earn at most 5/9)