



GCE

Mathematics (MEI)

Unit **4777**: Numerical Computation

Advanced GCE

Mark Scheme for June 2018

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This mark scheme is published as an aid to teachers and students, to indicate the requirements of the examination. It shows the basis on which marks were awarded by examiners. It does not indicate the details of the discussions which took place at an examiners' meeting before marking commenced.

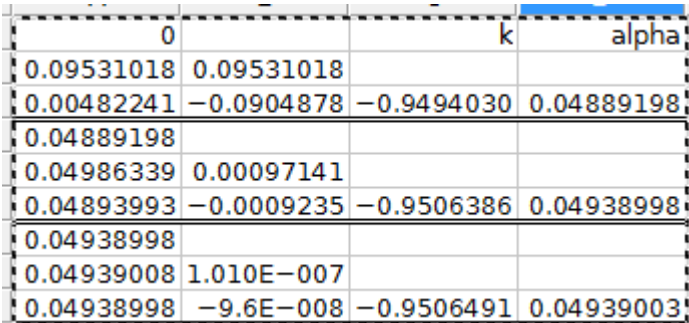
All examiners are instructed that alternative correct answers and unexpected approaches in candidates' scripts must be given marks that fairly reflect the relevant knowledge and skills demonstrated.

Mark schemes should be read in conjunction with the published question papers and the report on the examination.

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Annotations and abbreviations

Annotation in scoris	Meaning
✓ and ✕	
BOD	Benefit of doubt
FT	Follow through
ISW	Ignore subsequent working
M0, M1	Method mark awarded 0, 1
A0, A1	Accuracy mark awarded 0, 1
B0, B1	Independent mark awarded 0, 1
SC	Special case
^	Omission sign
MR	Misread
Highlighting	
Other abbreviations in mark scheme	Meaning
E1	Mark for explaining
U1	Mark for correct units
G1	Mark for a correct feature on a graph
M1 dep*	Method mark dependent on a previous mark, indicated by *
cao	Correct answer only
oe	Or equivalent
rot	Rounded or truncated
soi	Seen or implied
www	Without wrong working

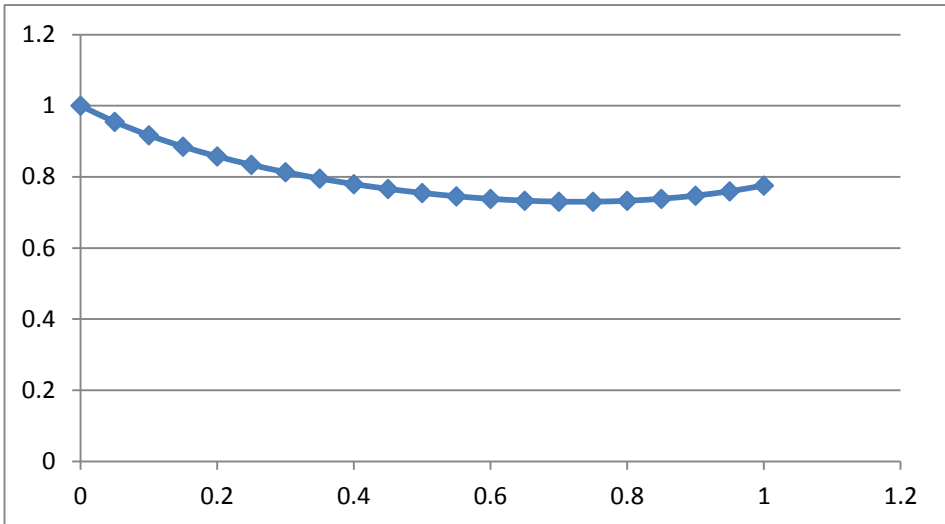
Question			Answer	Marks	Guidance																		
1	(i)		<p>Approx error in x_2 is $k^2\varepsilon$ $x_0 = \alpha + \varepsilon$</p> <p>$x_1 = \alpha + k\varepsilon$ $x_1 - x_0 = (k-1)\varepsilon$ $x_2 = \alpha + k^2\varepsilon$ $x_2 - x_1 = k(k-1)\varepsilon$ $(x_2 - x_1)/(x_1 - x_0) = k$</p> <p>Hence given expressions for α</p>	<p>B1 B1 B1 B1B1 B1 [6]</p>	<p>Expression for $x_{0,1,2}$ For Δx_0 For $\Delta x_1, k$</p>																		
1	(ii)		<p>Let $f(x) = \sin x + e^x$. Then $f'(x) = \cos x + e^x$. Note $f(0) = 1$, $f'(0) > 0$. $f'(x) = 0$ requires $\cos x = -e^x$, but $e^x > 1$ for $x > 0$. So f has no turning points for $x > 0$, and $f(x) = c > 1$ has a unique solution. Sketch of $\sin x + e^x$ to confirm this</p>	<p>B1 B1B1 B1 G1 [5]</p>																			
	(iii)		<p>Iterations with $c = 1.1$, very slow e.g.:</p> <table border="1"> <tr> <td>0</td><td>0.09531</td><td>0.004822</td><td>0.090917</td><td>0.009167</td><td>0.086942</td></tr> <tr> <td>0.1</td><td>0.000167</td><td>0.095159</td><td>0.004972</td><td>0.09078</td><td>0.009302</td></tr> <tr> <td>0.05</td><td>0.04881</td><td>0.049941</td><td>0.048866</td><td>0.049888</td><td>0.048916</td></tr> </table> <p>Set up and use method in part (i). E.g.:</p>	0	0.09531	0.004822	0.090917	0.009167	0.086942	0.1	0.000167	0.095159	0.004972	0.09078	0.009302	0.05	0.04881	0.049941	0.048866	0.049888	0.048916	<p>M1A1 B1 for a 2nd example</p>	
0	0.09531	0.004822	0.090917	0.009167	0.086942																		
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0.05	0.04881	0.049941	0.048866	0.049888	0.048916																		
			 <p>Root is 0.04939 to 4 sf</p>	<p>M2 for a correct spreadsheet A1A1A1 for three steps. A1 final answer</p> <p>[9]</p>																			

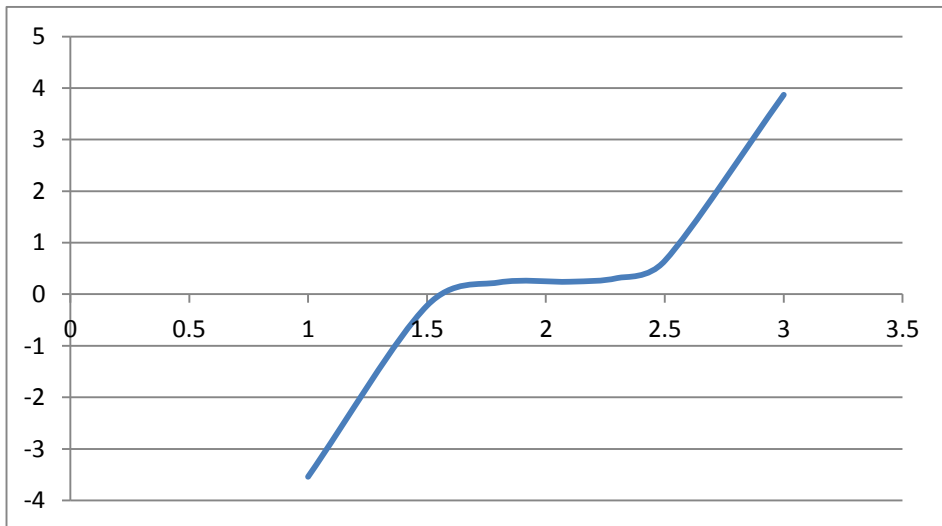
Question			Answer	Marks	Guidance													
1	(iv)		At least two examples with larger c , illustrating faster convergence. E.g. $c = 4$: <table><tr><td>1</td><td>1.150106</td><td>1.127262</td><td>1.130356</td><td>1.129929</td><td>1.129988</td></tr></table> E.g. $c = 8$: <table><tr><td>2</td><td>1.958784</td><td>1.956472</td><td>1.956349</td><td>1.956343</td><td>1.956342</td></tr></table>	1	1.150106	1.127262	1.130356	1.129929	1.129988	2	1.958784	1.956472	1.956349	1.956343	1.956342	M1A1 M1A1 [4]	Assessment	
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2	1.958784	1.956472	1.956349	1.956343	1.956342													
				[24]														

Question			Answer	Marks	Guidance																																																																																																																																																															
2	(i)		<p>Set up as $\int_{-h}^h f(x) dx = a f(-\alpha) + a f(\alpha)$</p> <p>$f(x) = 1$ $2h = 2a$ $a = h$</p> <p>$f(x) = x$, (and x^3) $0 = 0$</p> <p>$f(x) = x^2$ $2h^3 / 3 = 2a \alpha^2$ $\alpha = h / \sqrt{3}$</p> <p>Rule is exact up to cubics</p>	M1A1 B1 B1 B1 B1	 Answer given Answer given No reason required																																																																																																																																																															
				[6]																																																																																																																																																																
2	(ii)		<table><tr><th>a</th><th>b</th><th>m</th><th>h</th><th>L</th><th>R</th><th>f(L)</th><th>F(R)</th><th>G</th><th>Total</th></tr><tr><td>0</td><td>1</td><td>0.5</td><td>0.5</td><td>0.211325</td><td>0.788675</td><td>0.999004</td><td>0.849138</td><td>0.924071</td><td>0.924071</td></tr><tr><td>0</td><td>0.5</td><td>0.25</td><td>0.25</td><td>0.105662</td><td>0.394338</td><td>0.999938</td><td>0.988124</td><td>0.497016</td><td></td></tr><tr><td>0.5</td><td>1</td><td>0.75</td><td>0.25</td><td>0.605662</td><td>0.894338</td><td>0.938828</td><td>0.78093</td><td>0.429939</td><td>0.926955</td></tr><tr><td>0</td><td>0.25</td><td>0.125</td><td>0.125</td><td>0.052831</td><td>0.197169</td><td>0.999996</td><td>0.999245</td><td>0.249905</td><td></td></tr><tr><td>0.25</td><td>0.5</td><td>0.375</td><td>0.125</td><td>0.302831</td><td>0.447169</td><td>0.995821</td><td>0.980588</td><td>0.247051</td><td></td></tr><tr><td>0.5</td><td>0.75</td><td>0.625</td><td>0.125</td><td>0.552831</td><td>0.697169</td><td>0.956334</td><td>0.899391</td><td>0.231966</td><td></td></tr><tr><td>0.75</td><td>1</td><td>0.875</td><td>0.125</td><td>0.802831</td><td>0.947169</td><td>0.840535</td><td>0.744356</td><td>0.198111</td><td>0.927033</td></tr><tr><td>0</td><td>0.125</td><td>0.0625</td><td>0.0625</td><td>0.026416</td><td>0.098584</td><td>1</td><td>0.999953</td><td>0.124997</td><td></td></tr><tr><td>0.125</td><td>0.25</td><td>0.1875</td><td>0.0625</td><td>0.151416</td><td>0.223584</td><td>0.999737</td><td>0.998753</td><td>0.124906</td><td></td></tr><tr><td>0.25</td><td>0.375</td><td>0.3125</td><td>0.0625</td><td>0.276416</td><td>0.348584</td><td>0.997094</td><td>0.992698</td><td>0.124362</td><td></td></tr><tr><td>0.375</td><td>0.5</td><td>0.4375</td><td>0.0625</td><td>0.401416</td><td>0.473584</td><td>0.987265</td><td>0.97576</td><td>0.122689</td><td></td></tr><tr><td>0.5</td><td>0.625</td><td>0.5625</td><td>0.0625</td><td>0.526416</td><td>0.598584</td><td>0.963683</td><td>0.941395</td><td>0.119067</td><td></td></tr><tr><td>0.625</td><td>0.75</td><td>0.6875</td><td>0.0625</td><td>0.651416</td><td>0.723584</td><td>0.920549</td><td>0.885917</td><td>0.112904</td><td></td></tr><tr><td>0.75</td><td>0.875</td><td>0.8125</td><td>0.0625</td><td>0.776416</td><td>0.848584</td><td>0.856425</td><td>0.811498</td><td>0.104245</td><td></td></tr><tr><td>0.875</td><td>1</td><td>0.9375</td><td>0.0625</td><td>0.901416</td><td>0.973584</td><td>0.776095</td><td>0.725772</td><td>0.093867</td><td>0.927037</td></tr></table> <p>Integral is 0.9270 to 4 dp.</p> <p>Ratios of differences for these totals are 0.027212 and 0.047136</p> <p>Theory indicates $1/16 = 0.0625$ for a 4th order method. Not close (but approaches in the limit).</p>	a	b	m	h	L	R	f(L)	F(R)	G	Total	0	1	0.5	0.5	0.211325	0.788675	0.999004	0.849138	0.924071	0.924071	0	0.5	0.25	0.25	0.105662	0.394338	0.999938	0.988124	0.497016		0.5	1	0.75	0.25	0.605662	0.894338	0.938828	0.78093	0.429939	0.926955	0	0.25	0.125	0.125	0.052831	0.197169	0.999996	0.999245	0.249905		0.25	0.5	0.375	0.125	0.302831	0.447169	0.995821	0.980588	0.247051		0.5	0.75	0.625	0.125	0.552831	0.697169	0.956334	0.899391	0.231966		0.75	1	0.875	0.125	0.802831	0.947169	0.840535	0.744356	0.198111	0.927033	0	0.125	0.0625	0.0625	0.026416	0.098584	1	0.999953	0.124997		0.125	0.25	0.1875	0.0625	0.151416	0.223584	0.999737	0.998753	0.124906		0.25	0.375	0.3125	0.0625	0.276416	0.348584	0.997094	0.992698	0.124362		0.375	0.5	0.4375	0.0625	0.401416	0.473584	0.987265	0.97576	0.122689		0.5	0.625	0.5625	0.0625	0.526416	0.598584	0.963683	0.941395	0.119067		0.625	0.75	0.6875	0.0625	0.651416	0.723584	0.920549	0.885917	0.112904		0.75	0.875	0.8125	0.0625	0.776416	0.848584	0.856425	0.811498	0.104245		0.875	1	0.9375	0.0625	0.901416	0.973584	0.776095	0.725772	0.093867	0.927037	Up to 9 marks for this spreadsheet:
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Question			Answer	Marks	Guidance										
2	(iii)		Evidence of trial and improvement towards a solution. E.g. <table><tr><td>k</td><td>1.1</td><td>1.2</td><td>1.11</td><td>1.109</td></tr><tr><td>Int</td><td>0.9942</td><td>1.0546</td><td>1.0006</td><td>0.99993</td></tr></table> 1.11 to 2 dp	k	1.1	1.2	1.11	1.109	Int	0.9942	1.0546	1.0006	0.99993	M1 A1 at least one A1 others A1 answer [4]	
k	1.1	1.2	1.11	1.109											
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Question			Answer	Marks	Guidance																																																																																				
3	(i)		<div>Euler’s method with $h = 0.1$:</div> <table><thead><tr><th>h</th><th>x</th><th>y</th><th>y'</th></tr></thead><tbody><tr><td>0.1</td><td>0</td><td>0</td><td>0</td></tr><tr><td>0.1</td><td>0.1</td><td>0</td><td>0.001</td></tr><tr><td>0.1</td><td>0.2</td><td>0.0001</td><td>0.007996</td></tr><tr><td>0.1</td><td>0.3</td><td>0.0009</td><td>0.026919</td></tr><tr><td>0.1</td><td>0.4</td><td>0.003592</td><td>0.06343</td></tr><tr><td>0.1</td><td>0.5</td><td>0.009935</td><td>0.122565</td></tr><tr><td>0.1</td><td>0.6</td><td>0.022191</td><td>0.208296</td></tr><tr><td>0.1</td><td>0.7</td><td>0.043021</td><td>0.323136</td></tr><tr><td>0.1</td><td>0.8</td><td>0.075334</td><td>0.467899</td></tr><tr><td>0.1</td><td>0.9</td><td>0.122124</td><td>0.641681</td></tr><tr><td>0.1</td><td>1</td><td>0.186292</td><td>0.841947</td></tr></tbody></table> <div>Differences and ratio of differences:</div>	h	x	y	y'	0.1	0	0	0	0.1	0.1	0	0.001	0.1	0.2	0.0001	0.007996	0.1	0.3	0.0009	0.026919	0.1	0.4	0.003592	0.06343	0.1	0.5	0.009935	0.122565	0.1	0.6	0.022191	0.208296	0.1	0.7	0.043021	0.323136	0.1	0.8	0.075334	0.467899	0.1	0.9	0.122124	0.641681	0.1	1	0.186292	0.841947	M2 Set up A1 1 st run A1 2 nd A1 3rd																																					
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			Ratio of 0.5 indicates first order method.	E1																																																																																					
				8																																																																																					
3	(ii)		<div>Modified Euler method with $h = 0.1$:</div> <table><thead><tr><th>h</th><th>x</th><th>y</th><th>y'</th><th>$x+$</th><th>$y+$</th><th>$y+'$</th></tr></thead><tbody><tr><td>0.1</td><td>0</td><td>0</td><td>0</td><td>0.1</td><td>0</td><td>0.001</td></tr><tr><td>0.1</td><td>0.1</td><td>0.00005</td><td>0.001</td><td>0.2</td><td>0.00015</td><td>0.007994</td></tr><tr><td>0.1</td><td>0.2</td><td>0.0005</td><td>0.00798</td><td>0.3</td><td>0.001298</td><td>0.026884</td></tr><tr><td>0.1</td><td>0.3</td><td>0.002243</td><td>0.0268</td><td>0.4</td><td>0.004923</td><td>0.063222</td></tr><tr><td>0.1</td><td>0.4</td><td>0.006744</td><td>0.062939</td><td>0.5</td><td>0.013038</td><td>0.121823</td></tr><tr><td>0.1</td><td>0.5</td><td>0.015982</td><td>0.121128</td><td>0.6</td><td>0.028095</td><td>0.206337</td></tr><tr><td>0.1</td><td>0.6</td><td>0.032355</td><td>0.204946</td><td>0.7</td><td>0.05285</td><td>0.318911</td></tr><tr><td>0.1</td><td>0.7</td><td>0.058548</td><td>0.31651</td><td>0.8</td><td>0.090199</td><td>0.460047</td></tr><tr><td>0.1</td><td>0.8</td><td>0.097376</td><td>0.456342</td><td>0.9</td><td>0.14301</td><td>0.628644</td></tr><tr><td>0.1</td><td>0.9</td><td>0.151625</td><td>0.623389</td><td>1</td><td>0.213964</td><td>0.822021</td></tr><tr><td>0.1</td><td>1</td><td>0.223896</td><td>0.81501</td><td>1.1</td><td>0.305397</td><td>1.03558</td></tr></tbody></table>	h	x	y	y'	$x+$	$y+$	$y+'$	0.1	0	0	0	0.1	0	0.001	0.1	0.1	0.00005	0.001	0.2	0.00015	0.007994	0.1	0.2	0.0005	0.00798	0.3	0.001298	0.026884	0.1	0.3	0.002243	0.0268	0.4	0.004923	0.063222	0.1	0.4	0.006744	0.062939	0.5	0.013038	0.121823	0.1	0.5	0.015982	0.121128	0.6	0.028095	0.206337	0.1	0.6	0.032355	0.204946	0.7	0.05285	0.318911	0.1	0.7	0.058548	0.31651	0.8	0.090199	0.460047	0.1	0.8	0.097376	0.456342	0.9	0.14301	0.628644	0.1	0.9	0.151625	0.623389	1	0.213964	0.822021	0.1	1	0.223896	0.81501	1.1	0.305397	1.03558	M3 set up A1 1 st run A1 2 nd A1 3rd	
h	x	y	y'	$x+$	$y+$	$y+'$																																																																																			
0.1	0	0	0	0.1	0	0.001																																																																																			
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Question			Answer	Marks	Guidance																		
			Differences and ratios of differences:																				
			<table><tr><th>h</th><th>y(1)</th><th>diffs</th><th>ratio of diffs</th></tr><tr><td>0.1</td><td>0.223896</td><td></td><td></td></tr><tr><td>0.05</td><td>0.22212</td><td>-0.00178</td><td></td></tr><tr><td>0.025</td><td>0.221687</td><td>-0.00043</td><td>0.243497</td></tr></table> <p>Ratio of 0.25 indicates second order method.</p>	h	y(1)	diffs	ratio of diffs	0.1	0.223896			0.05	0.22212	-0.00178		0.025	0.221687	-0.00043	0.243497	B1 E1 [8]			
h	y(1)	diffs	ratio of diffs																				
0.1	0.223896																						
0.05	0.22212	-0.00178																					
0.025	0.221687	-0.00043	0.243497																				
3	(iii)		<div></div> <p>Minimum points for reducing h:</p> <table><tr><th>h</th><th>x</th><th>y</th></tr><tr><td>0.1</td><td>0.7</td><td>0.731079</td></tr><tr><td>0.05</td><td>0.75</td><td>0.729895</td></tr><tr><td>0.025</td><td>0.725</td><td>0.729388</td></tr><tr><td>0.0125</td><td>0.725</td><td>0.729321</td></tr><tr><td>0.00625</td><td>0.73125</td><td>0.729297</td></tr></table> <p>(0.73, 0.73) seems safe to 2 dp. $x = y$ at the minimum is to be expected because that makes y' zero</p>	h	x	y	0.1	0.7	0.731079	0.05	0.75	0.729895	0.025	0.725	0.729388	0.0125	0.725	0.729321	0.00625	0.73125	0.729297	M1A1 G2 M1A1 A1 E1	New values soi NB: the curve rises slightly if too large a value of h is used.
h	x	y																					
0.1	0.7	0.731079																					
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				[8]																			
				[24]																			

Question			Answer	Marks	Guidance																																																
4	(i)		<div>Sketch of data points;</div> <div></div> <div>Appears roughly cubic</div>	G2 B1 [3]																																																	
	(ii)		<div>Ordinary differences require equal spacing.</div> <div>Lagrange's method is computational intensive.</div> <div>Divided differences allow unequal spacing and increasing the degree is easy</div>	E1 E1 E1 [3]																																																	
	(iii)		<div>Divided difference table:</div> <table><tr><th>x</th><th>f</th><th>1DD</th><th>2DD</th><th>3DD</th><th>4DD</th></tr><tr><td>1</td><td>-3.542</td><td></td><td></td><td></td><td></td></tr><tr><td>1.5</td><td>-0.224</td><td>6.636</td><td></td><td></td><td></td></tr><tr><td>1.8</td><td>0.226</td><td>1.5</td><td>-6.42</td><td></td><td></td></tr><tr><td>2.1</td><td>0.241</td><td>0.05</td><td>-2.41667</td><td>3.639394</td><td></td></tr><tr><td>2.3</td><td>0.312</td><td>0.355</td><td>0.61</td><td>3.783333</td><td>0.110723</td></tr><tr><td>2.5</td><td>0.647</td><td>1.675</td><td>3.3</td><td>3.842857</td><td>0.059524</td></tr><tr><td>3</td><td>3.867</td><td>6.44</td><td>6.807143</td><td>3.896825</td><td>0.044974</td></tr></table> <div>Similar 3DDs suggests cubic should be a good fit.</div>	x	f	1DD	2DD	3DD	4DD	1	-3.542					1.5	-0.224	6.636				1.8	0.226	1.5	-6.42			2.1	0.241	0.05	-2.41667	3.639394		2.3	0.312	0.355	0.61	3.783333	0.110723	2.5	0.647	1.675	3.3	3.842857	0.059524	3	3.867	6.44	6.807143	3.896825	0.044974	B1 B1 B1 E1 [4]	1DD 2DD 3DD
x	f	1DD	2DD	3DD	4DD																																																
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Question			Answer	Marks	Guidance																																																				
4	(iv)	(A)	<p>To estimate $f(2)$:</p> <table><tr><th>x</th><th>f</th><th>1DD</th><th>2DD</th><th>3DD</th><th>4DD</th></tr><tr><td>2.1</td><td>0.241</td><td></td><td></td><td></td><td></td></tr><tr><td>1.8</td><td>0.226</td><td>0.05</td><td></td><td></td><td></td></tr><tr><td>2.3</td><td>0.312</td><td>0.172</td><td>0.61</td><td></td><td></td></tr><tr><td>2.5</td><td>0.647</td><td>1.675</td><td>2.147143</td><td>3.842857</td><td></td></tr><tr><td>1.5</td><td>-0.224</td><td>0.871</td><td>1.005</td><td>3.807143</td><td>0.0595238</td></tr></table>	x	f	1DD	2DD	3DD	4DD	2.1	0.241					1.8	0.226	0.05				2.3	0.312	0.172	0.61			2.5	0.647	1.675	2.147143	3.842857		1.5	-0.224	0.871	1.005	3.807143	0.0595238	Modify order of data in table B1																	
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(B)	<table><tr><td>x =</td><td>2</td><td></td><td></td><td></td><td></td></tr><tr><td>f(x) =</td><td>0.241</td><td>0.236</td><td>0.2238</td><td>0.246857</td><td>0.2466786</td></tr><tr><td></td><td></td><td>linear</td><td>quadratic</td><td>cubic</td><td>quartic</td></tr></table> <p>0.247 or 0.25 seem safe estimates</p> <p>To estimate $f(2.7)$:</p> <table><tr><th>x</th><th>f</th><th>1DD</th><th>2DD</th><th>3DD</th><th>4DD</th></tr><tr><td>2.5</td><td>0.647</td><td></td><td></td><td></td><td></td></tr><tr><td>3</td><td>3.867</td><td>6.44</td><td></td><td></td><td></td></tr><tr><td>2.3</td><td>0.312</td><td>5.078571</td><td>6.807143</td><td></td><td></td></tr><tr><td>2.1</td><td>0.241</td><td>0.355</td><td>5.248413</td><td>3.896825</td><td></td></tr><tr><td>1.8</td><td>0.226</td><td>0.05</td><td>0.61</td><td>3.865344</td><td>0.0449735</td></tr></table>	x =	2					f(x) =	0.241	0.236	0.2238	0.246857	0.2466786			linear	quadratic	cubic	quartic	x	f	1DD	2DD	3DD	4DD	2.5	0.647					3	3.867	6.44				2.3	0.312	5.078571	6.807143			2.1	0.241	0.355	5.248413	3.896825		1.8	0.226	0.05	0.61	3.865344	0.0449735	A1A1A1A1 A1	
x =	2																																																								
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x =	2.7																																																								
f(x) =	0.647	1.935	1.526571	1.433048	1.4324																																																				
		linear	quadratic	cubic	quartic																																																				
	(v)		<p>To estimate x such that $f(x) = 0$, intelligent trial and error leading to something like:</p> <table><tr><th>x</th><th>f</th><th>1DD</th><th>2DD</th><th>3DD</th><th>4DD</th></tr><tr><td>1.5</td><td>-0.224</td><td></td><td></td><td></td><td></td></tr><tr><td>1.8</td><td>0.226</td><td>1.5</td><td></td><td></td><td></td></tr><tr><td>2.1</td><td>0.241</td><td>0.05</td><td>-2.41667</td><td></td><td></td></tr><tr><td>1</td><td>-3.542</td><td>3.439091</td><td>-4.23636</td><td>3.639394</td><td></td></tr><tr><td>2.3</td><td>0.312</td><td>2.964615</td><td>-2.37238</td><td>3.727972</td><td>0.1107226</td></tr></table>	x	f	1DD	2DD	3DD	4DD	1.5	-0.224					1.8	0.226	1.5				2.1	0.241	0.05	-2.41667			1	-3.542	3.439091	-4.23636	3.639394		2.3	0.312	2.964615	-2.37238	3.727972	0.1107226	Modify order of data in table A1 Try values of x M1 A1 A1 [4] [24]																	
x	f	1DD	2DD	3DD	4DD																																																				
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