1761

De integratione aequationis differentialis $(m\,dx)/\sqrt{(1-x^4)} = (n\,dy)/\sqrt{(1-y^4)}$

Leonhard Euler

DE INTEGRATIONE AEQVATIONIS DIFFERENTIALIS.

$$\frac{m\,dx}{\sqrt{(1-x^4)}} = \frac{n\,dy}{\sqrt{(1-y^4)}}$$

Auctore

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§. 1.

Cum primum occaſione inuentionum Ill. Comitis Fagnani hanc aequationem eſſem contemplatus, eiusmodi quidem relationem algebraicam inter variabiles x et y elicui, quae huic aequationi ſatisfaceret; ſed ea relatio non pro aequatione integrali completa haberi poterat, propterea quod non complecteretur quantitatem conſtantem arbitrariam, cuiusmodi ſemper in calculum per integrationem introduci ſolet. Hinc enim, vti ſatis notum eſt, integralia incompleta et particularia diſtingui ſolent, quorum illa totam vim aequationum differentialium exhauriunt, haec vero tantum ita ſatisfaciunt, vt aliae inſuper expreſſiones aeque ſatisfacere queant. Criterium autem aequationis integralis completae in hoc conſiſtit, quod ea quantitatem conſtantem inuoluere debeat, quae in aequatione differentiali non apparet.

§. 2. Quae quo clarius perſpiciantur, ſufficiet, aequationem differentialem ſimpliciſſimam $dx = dy$ conſideraſſe, cui vtique ſatisfacit haec integralis $x = y$, in rem tamen haec integralis minus late patet, quam differentialis $dx = dy$, cum huic aeque ſatisfaciat haec integralis $x = y + a$ multo latius patens, ſumendo pro a quantitatem conſtantem quamcunque, atque haec demum integralis totam vim aequationis differentialis $dx = dy$ exhaurire cenſetur, ex quo etiam aequatio integralis completa appellatur; propterea quod in ea ineſt quantitas conſtans a, quae in aequatione differentiali non occurrit. Quodſi vero loco iſtius conſtantis indefinitae a valores determinati ſubſtituantur, ex integrali completo obtinentur integralia particularia, quae ob hanc ipſam rationem minus late patent, quam aequatio differentialis propoſita.

§. 3. Saepe numero autem aequationis differentialis integrale particulare algebraicum exhiberi poteſt, cum tamen integrale completum ſit tranſcendens; hoc ſcilicet euenit, ſi pars tranſcendens per conſtantem illam arbitrariam fuerit multiplicata, quae propterea, conſtante illa nihilo aequali poſita, ex calculo euaneſcit, et integrale algebraicum particulare relinquit. Ita huic aequationi $dy = dx + (y - x)dx$ manifeſtum eſt; ſatisfacere valorem $y = x$, quo tamen tantum integrale particulare continetur, cum completum ſit $y = x + ae^x$, denotante e numerum, cuius logarithmus eſt $= 1$. Niſi igitur conſtans arbitraria a euaneſcens ponatur, integrale ſemper erit tranſcendens.

§. 4. Cum igitur euenire queat, vt aequatio differentialis integrale particulare algebraicum admittat, etiamsi integrale completum sit transcendens, ita etiam rationes dubitandi non desunt, quod integrale completum aequationis differentialis propositae $\frac{m\,dx}{\sqrt{(1-x^4)}} = \frac{n\,dy}{\sqrt{(1-y^4)}}$ quantitates transcendentes inuoluat, etiamsi pro ea integrale particulare algebraicum exhibere licuerit. Cum enim integrale completum sit:

$$m\int\frac{dx}{\sqrt{(1-x^4)}} = n\int\frac{dy}{\sqrt{(1+y^4)}} + C$$

haec autem integralia nullo modo, neque circuli, neque hyperbolae, quadraturam in subsidium vocando, assignari queant, minime probabile videtur, istas formulas tantopere transcendentes in genere, ita vt constans C maneat indeterminata, ad relationem algebraicam inter x et y reuocari posse.

§. 5. Notum quidem est, integrale completum huius aequationis differentialis $\frac{m\,dx}{\sqrt{(1-xx)}} = \frac{n\,dy}{\sqrt{(1-yy)}}$ semper algebraice exhiberi posse, dummodo proportio coefficientium m et n fuerit rationalis; sed quia vtriusque formulae integrale arcum circuli indicat, ita vt integrale completum sit $m\,\mathrm{A}\,\sin.\,x = n\,\mathrm{A}\,\sin.\,y + C$, relatio autem sinuum, qui ad arcus proportionem rationalem inter se tenentes spectant, algebraice exprimi potest, mirum non est, aequationem integralem completam his casibus quoque algebraice exhiberi posse. Cum autem huiusmodi comparatio in formulis transcendentibus $\int\frac{dx}{\sqrt{(1-x^4)}}$ et $\int\frac{dy}{\sqrt{(1-y^4)}}$ locum non habeat, seu saltem non conſtet, inde reductio integralis ad quantitates algebraicas peti non poterit.

§. 6. Nihilo tamen minus obſeruaui, ſi propoſita fuerit huiusmodi aequatio differentialis

$$\frac{m\,dx}{\sqrt{(1-x^4)}} = \frac{n\,dy}{\sqrt{(1-y^4)}}$$

etiam integrale completum, quod ſcilicet quantitatem conſtantem arbitrariam inuoluat, ſemper algebraice exprimi poſſe, dummodo ratio $m:n$ fuerit rationalis: quod mihi quidem eo magis notatu dignum videtur, quod nulla certa methodo ad hoc integrale ſum perductus, ſed id potius tentando, vel diuinando, elicui. Vnde nullum eſt dubium, quin methodus directa, ad idem hoc integrale perducens, fines analyſeos non mediocriter ſit amplificatura; cuius propterea inueſtigatio Analyſtis omni ſtudio commendanda videtur.

§. 7. Completum autem integrale aequationis iſtius differentialis, quaecunque fuerit ratio rationalis coëfficientium m et n, deriuare mihi licuit ex integratione completa huius aequationis $\frac{dx}{\sqrt{(1-x^4)}} = \frac{dy}{\sqrt{(1-y^4)}}$: hac enim conceſſa methodum certam indicabo, ex ea quoque integrale completum huius aequationis multo latius patentis $\frac{m\,dx}{\sqrt{(1-x^4)}} = \frac{n\,dy}{\sqrt{(1-y^4)}}$ concludendi. Quae methodus etiam in genere ad huiusmodi aequationum $mX\,dx = nY\,dy$ integralia inuenienda adhiberi queat, ſi modo integrale completum huius $X\,dx = Y\,dy$ fuerit erutum, atque Y talem ſignificet functionem ipſius y, qualis X eſt ipſius x.

§. 8.

§. 8. Exordiar igitur ab hac aequatione

$$\frac{dx}{\sqrt{(1-x^4)}} = \frac{dy}{\sqrt{(1-y^4)}}$$

cui quidem primo intuitu satisfacere perspicuum est aequationem $x = y$, quae propterea eius est integrale particulare. Tum vero eidem aequationi quoque satisfacit iste valor algebraicus $x = -\sqrt{\frac{1-yy}{1+yy}}$, cum enim sit $dx = +\frac{2y\,dy}{(1+yy)\sqrt{(1-yy)(1+yy)}}$ et $\sqrt{(1-x^4)} = \frac{2y}{1+yy}$ erit $\frac{dx}{\sqrt{(1-x^4)}} = \frac{dy}{\sqrt{(1-y^4)}}$. Hinc iste etiam valor, seu aequatio $xxyy + xx + yy - 1 = 0$ est integralis particularis aequationis differentialis propositae. Vnde integrale completum, quod constantem arbitrariam inuoluat, ita comparatum sit necesse est, vt tribuendo huic constanti certum quendam valorem, prodeat $x = y$; sin autem eidem constanti alius quidem valor tribuatur, vt prodeat $x = -\sqrt{\frac{1-yy}{1+yy}}$ seu $xxyy + xx + yy - 1 = 0$.

Theorema.

§. 9. Dico igitur huius aequationis differentialis

$$\frac{dx}{\sqrt{(1-x^4)}} = \frac{dy}{\sqrt{(1-y^4)}}$$

aequationem integralem completam esse:

$$xx + yy + ccxxyy = cc + 2xy\sqrt{(1-c^4)}$$

Demonstratio.

Posita enim hac aequatione, eius differentiale erit:

$$xdx + ydy + ccxy(xdy + ydx) = (xdy + ydx)\sqrt{(1-c^4)}$$

 vnde

vnde fit

$$dx(x + ccxyy - y\sqrt{(1-c^4)}) + dy(y + ccxxy - x\sqrt{(1-c^4)}) = 0$$

Ex eadem vero aequatione resoluta colligitur:

$$y = \frac{x\sqrt{(1-c^4)} + c\sqrt{(1-x^4)}}{1 + ccxx}$$

$$\text{et } x = \frac{y\sqrt{(1-c^4)} - c\sqrt{(1-y^4)}}{1 + ccyy}$$

Si enim ibi radicali $\sqrt{(1-x^4)}$ tribuitur signum $+$, hic radicali $\sqrt{(1-y^4)}$ signum $-$ tribui debet; vt posito $x = 0$, vtrinque idem valor prodeat $y = c$. Erit ergo

$$x + ccxyy - y\sqrt{(1-c^4)} = -c\sqrt{(1-y^4)}$$

$$y + ccxxy - x\sqrt{(1-c^4)} = c\sqrt{(1-x^4)}$$

quibus valoribus in aequatione differentiali substitutis, prodit

$$-cdx\sqrt{(1-y^4)} + cdy\sqrt{(1-x^4)} = 0,$$

siue $\frac{dx}{\sqrt{(1-x^4)}} = \frac{dy}{\sqrt{(1-y^4)}}$.

Huius ergo aequationis differentialis integrale est:

$$xx + yy + ccxxyy = cc + 2xy\sqrt{(1-c^4)}$$

et quia constantem c ab arbitrio nostro pendentem continet, erit simul integrale completum. Q. E. D.

§. 10. Si igitur habeatur haec aequatio $\frac{dx}{\sqrt{(1-x^4)}} = \frac{dy}{\sqrt{(1-y^4)}}$ valor integralis completus ipsius x est:

$$x = \frac{y\sqrt{(1-c^4)} \pm c\sqrt{(1-y^4)}}{1 + ccyy}$$

vnde si constans arbitraria c euanescat fit $x = y$; sin autem ponatur $c = 1$, habemus $x = \pm \frac{\sqrt{(1-y^4)}}{1+yy} = \sqrt{\frac{1-yy}{1+yy}}$ qui sunt ambo illi valores particulares iam supra exhibiti.

biti. Hinc eruuntur alii valores particulares prae caeteris simpliciores, sed qui ad imaginaria deuoluuntur. Ita

posito $c = \infty$ fit $x = \frac{\sqrt{-1}}{y}$; et

posito $cc = -1$; fit $x = \sqrt{\frac{yy+1}{yy-1}}$

qui itidem aequationi propositae satisfaciunt.

§. 11. Quo autem ratio huius integralis clarius perspiciatur, concipiatur curua AM cuius haec sit indoles, vt posita abscissa $AP = u$, sit arcus ei respondens $AM = \int \frac{du}{\sqrt{(1-u^4)}}$. Deinde eadem curua denuo descripta, capiatur abscissa $ap = x$, erit arcus $am = \int \frac{dx}{\sqrt{(1-x^4)}}$. Sumto igitur Tab. I. Fig. 1. 2.

$$x = \frac{u\sqrt{(1-c^4)} \pm c\sqrt{(1-u^4)}}{1+ccuu}$$

fiet $\frac{dx}{\sqrt{(1-x^4)}} = \frac{du}{\sqrt{(1-u^4)}}$; ideoque arc. am = arc. AM + Const. Pro constantis autem huius determinatione, posito $u = 0$ quo casu arcus AM euanescit, fit $x = c$. Quare si capiatur abscissa $ab = c$; cui arcus ad respondeat, erit arcus dm = arcui AM.

§. 12. Ope huius ergo integrationis completa aequationis $\frac{dx}{\sqrt{(1-x^4)}} = \frac{du}{\sqrt{(1-u^4)}}$, in curua proposita arcui cuicunque AM, qui abscissae $AP = u$ respondet, arcus aequalis dm, qui a dato puncto d incipiat, abscindi poterit. Posita enim abscissa dato puncto d respondente $ab = c$; si capiatur abscissa $ap = x = \frac{c\sqrt{(1-u^4)}+u\sqrt{(1-c^4)}}{1+ccuu}$ erit arcus dm arcui AM aequalis. Simili autem modo cum $\sqrt{(1-c^4)}$ negatiuum statui liceat, si capiatur abscissa

$$a\pi = \frac{c\sqrt{(1-u^4)} - u\sqrt{(1-c^4)}}{1+ccuu}$$

 erit

erit itidem arcus $d\mu$ arcui AM aequalis: sicque in hac curua a dato quouis puncto d vtrinque abscindi potest arcus dm et $d\mu$, qui arcui AM sint aequales.

§. 13. Hinc ergo patet, si arcus ad aequalis capiatur arcui AM, seu $c = u$, fore arcum am duplum arcus AM. Hinc si statuatur $ap = x = \frac{2u\sqrt{(1-u^4)}}{1+u^4}$, prodibit arcus $am = 2$ arc. AM. Simili modo si capiatur arcus $ad = 2$ AM, seu $c = \frac{2u\sqrt{(1-u^4)}}{1+u^4}$, statuaturque $x = \frac{c\sqrt{(1-u^4)}+u\sqrt{(1-c^4)}}{1+ccuu}$ obtinebitur arcus $am = 3$ arc. AM. Ac si iste valor ipsius x denuo pro c substituatur, vt fit $ad = 3$ AM iterumque statuatur $x = \frac{c\sqrt{(1-u^4)}+u\sqrt{(1-c^4)}}{1+ccuu}$; nascetur arcus am quadruplus arcus AM; atque ita porro successiue quaecunque multipla arcus AM geometrice assignari poterunt.

§. 14. Sit arcus $ad = n$. AM et $ab = z$; ita vt sit $\int.\frac{dz}{\sqrt{(1-z^4)}} = n\int\frac{du}{\sqrt{(1-u^4)}}$; atque ex his patet si capiatur $x = \frac{z\sqrt{(1-u^4)}+u\sqrt{(1-z^4)}}{1+uuzz}$ fore $\int\frac{dx}{\sqrt{(1-x^4)}} = (n+1)\int\frac{du}{\sqrt{(1-u^4)}}$; sin autem ponatur $x = \frac{z\sqrt{(1-u^4)}-u\sqrt{(1-z^4)}}{1+uuzz}$, tum futurum esse $\int\frac{dx}{\sqrt{(1-x^4)}} = (n-1)\int\frac{du}{\sqrt{(1-u^4)}}$. Si igitur haec aequatio $\frac{dz}{\sqrt{(1-z^4)}} = \frac{n\,du}{\sqrt{(1-u^4)}}$ fuerit integrata, debitusque valor pro z inde erutus, etiam integrari poterit haec aequatio $\frac{dx}{\sqrt{(1-x^4)}} = \frac{(n\pm1)\,du}{\sqrt{(1-u^4)}}$, quippe cuius integrale erit $x = \frac{z\sqrt{(1-u^4)}\pm u\sqrt{(1-z^4)}}{1+uuzz}$. Ac si pro z assumtus fuerit eius valor completus, qui scilicet constantem arbitrariam inuoluat, etiam pro x prodibit eius valor completus.

§. 15. Hinc igitur perspicuum est, quomodo aequatio integralis completa inueniri debeat, quae conueniat huic aequationi differentiali $\frac{dx}{\sqrt{(1-x^4)}} = \frac{n\,du}{\sqrt{(1-u^4)}}$; quoties n fuerit numerus integer. Simili autem modo assignari poterit y, vt fit $\frac{dy}{\sqrt{(1-y^4)}} = \frac{m\,du}{\sqrt{(1-u^4)}}$, vnde si eliminando u, aequatio inter x et y quaeratur, ea erit integralis huius aequationis $\frac{m\,dx}{\sqrt{(1-x^4)}} = \frac{n\,dy}{\sqrt{(1-y^4)}}$, quicunque numeri rationales pro m et n substituantur: atque vt hoc integrale prodeat completum, sufficit pro altera tantum variabilium x et y valorem completum per u determinasse, cum hinc iam noua constans arbitraria in calculum introducatur.

§. 16. Methodus, qua hic in Theorematis demonstratione sum vsus, etsi non ex rei natura est petita, sed indirecte ad id, quod propositum erat, perduxit, tamen multo latius patet: simili enim modo colligitur, huius aequationis differentialis

$$\frac{dx}{\sqrt{(1+mxx+nx^4)}} = \frac{dy}{\sqrt{(1+myy+ny^4)}},$$

integrale completum esse:

$$0 = cc - xx - yy + nccxxyy + 2xy\sqrt{(1+mcc+nc^4)}.$$

Vnde idem, quod ante, ratiocinium adhibendo, integrale quoque completum obtinebitur huius aequationis

$$\frac{\mu\,dx}{\sqrt{(1+mxx+nx^4)}} = \frac{\nu\,dy}{\sqrt{(1+myy+ny^4)}},$$

siquidem litteris μ et ν numeri integri designentur.

§. 17. Inuestigatio autem huius integrationis ita se habet: Fingatur primo pro arbitrio relatio inter variabiles x et y hac aequatione contenta:

$$(1)\quad \alpha xx + \alpha yy = 2\beta xy + \gamma xxyy + \delta$$

quae differentiata dat:

$$\alpha x dx + \alpha y dy = \beta x dy + \beta y dx + \gamma xyy dx + \gamma xxy dy$$

vnde conficitur

$$(2)\quad dx(\alpha x - \beta y - \gamma xyy) + dy(\alpha y - \beta x - \gamma xxy) = 0$$

Deinde ex aequatione (1) eliciantur valores vtriusque variabilis:

$$x = \frac{\beta y + \surd(\alpha\delta + (\beta\beta - \alpha\alpha - \gamma\delta)yy + \alpha\gamma y^4)}{\alpha - \gamma yy}$$

$$y = \frac{\beta x - \surd(\alpha\delta + (\beta\beta - \alpha\alpha - \gamma\delta)xx + \alpha\gamma x^4)}{\alpha - \gamma xx}$$

Atque hinc obtinemus:

$$(3).\quad \alpha x - \beta y - \gamma xyy = \surd(\alpha\delta + (\beta\beta - \alpha\alpha - \gamma\delta)yy + \alpha\gamma y^4)$$

$$(4).\quad \alpha y - \beta x - \gamma xxy = -\surd(\alpha\delta + (\beta\beta - \alpha\alpha - \gamma\delta)xx + \alpha\gamma x^4)$$

qui valores in aequatione (2) substituti praebebunt

$$(5).\quad \frac{dx}{\surd(\alpha\delta + (\beta\beta - \alpha\alpha - \gamma\delta)xx + \alpha\gamma x^4)} = \frac{dy}{\surd(\alpha\delta + (\beta\beta - \alpha\alpha - \gamma\delta)yy + \alpha\gamma y^4)}$$

cuius ergo aequationis integrale est aequatio (1).

§. 18. Quo istas formas simpliciores reddamus, ponamus $\alpha\delta = A$; $\beta\beta - \alpha\alpha - \gamma\delta = C$; $\alpha\gamma = E$ eritque $\delta = \frac{A}{\alpha}$; $\gamma = \frac{E}{\alpha}$ et $\beta = \surd(C + \alpha\alpha + \frac{AE}{\alpha\alpha})$ Quare huius aequationis differentialis

$$(6)\quad \frac{dx}{\surd(A + Cxx + Ex^4)} = \frac{dy}{\surd(A + Cyy + Ey^4)}$$

aequatio integralis est haec;

$$(7).\quad \alpha(xx + yy) = \frac{A}{\alpha} + \frac{E}{\alpha}xxyy + 2xy\surd(C + \alpha\alpha + \frac{AE}{\alpha\alpha})$$

quae simul est integralis completa:

§. 19. Vel ponamus $A = f\alpha\alpha$: $C = g\alpha\alpha$ et $E = h\alpha\alpha$, vt habeamus hanc aequationem differentialem

$$\frac{dx}{\surd(f + gxx + hx^4)} = \frac{dy}{\surd(f + gyy + hy^4)}$$

cuius

cuius propterea aequatio integralis completa erit:

$$xx + yy = f + hxxyy + 2xy\sqrt{(1 + g + fh)}$$

quae etsi nouam constantem inuoluere non videtur, tamen est completa, cum in differentiali tantum ratio quantitatum f, g, et h spectatur, ita vt pro f, g, et h scribere liceat fcc, gcc et hcc, vnde aequatio integralis manifesto completa prodit:

$$xx + yy = fcc + hccxxyy + 2xy\sqrt{(1 + gcc + fhc^4)}$$

vel $f(xx + yy) = fee + heexxyy + 2xy\sqrt{f(f + gee + he^4)}$ posito $cc = \frac{ee}{f}$.

§. 20. Quodsi ergo proposita sit haec aequatio differentialis

$$\frac{dx}{\sqrt{(f + gxx + hx^4)}} = \frac{dy}{\sqrt{(f + gyy + hy^4)}}$$

valor ipsius y per functionem algebraicam ipsius x exprimi poterit, ita vt sit:

$$y = \frac{x\sqrt{(1 + gcc + fhc^4)} \pm c\sqrt{(f + gxx + hx^4)}}{1 - hccxx}$$

$$\text{vel } y = \frac{x\sqrt{f(f + gee + he^4)} \pm e\sqrt{f(f + gxx + hx^4)}}{f - heexx}$$

Quodsi ergo sit $g = 0$, vt habeatur haec aequatio differentialis

$$\frac{dx}{\sqrt{(f + hx^4)}} = \frac{dy}{\sqrt{(f + hy^4)}}$$

valor integralis completus ipsius y erit

$$y = \frac{x\sqrt{f(f + he^4)} \pm e\sqrt{f(f + hx^4)}}{f - heexx}$$

vnde constantem e pro lubitu determinando, innumeri valores particulares pro y deduci possunt.

§. 21.

§. 21. Methodi autem, qua ſupra vſus ſum, beneficio etiam huius aequationis

$$\frac{m\,dx}{\sqrt{(f+gxx+hx^4)}} = \frac{n\,dy}{\sqrt{(f+gyy+hy^4)}}$$

ſi modo m et n ſint numeri rationales, integrale completum, atque id quidem algebraice, exhiberi poterit.

§. 22. Quemadmodum in aequatione ſupra aſſumta, variabiles x et y inter ſe permutabiles ſunt conſtitutae, vt ambae formulae inter ſe ſimiles euaderent, ita omiſſa hac limitatione ad formularum differentialium diſparium comparationem perueniemus. Ponamus ergo:

(1) $\alpha xx + \beta yy = 2\gamma xy + \delta xxyy + \varepsilon$

vnde fit

$$x = \frac{\gamma y + \sqrt{(\alpha\varepsilon + (\gamma\gamma - \delta\varepsilon - \alpha\beta)yy + \beta\delta y^4)}}{\alpha - \delta yy}$$

et $y = \frac{\gamma x - \sqrt{(\beta\varepsilon + (\gamma\gamma - \delta\varepsilon - \alpha\beta)xx + \alpha\delta x^4)}}{\beta - \delta xx}$

hincque

(2) $\alpha x - \gamma y - \delta xyy = \sqrt{(\alpha\varepsilon + (\gamma\gamma - \delta\varepsilon - \alpha\beta)yy + \beta\delta y^4)}$

(3) $\beta y - \gamma x - \delta xxy = -\sqrt{(\beta\varepsilon + (\gamma\gamma - \delta\varepsilon - \alpha\beta)xx + \alpha\delta x^4)}$

at aequatio (1) differentiata dat:

$$dx(\alpha x - \gamma y - \delta xyy) + dy(\beta y - \gamma x - \delta xxy) = 0$$

vnde conficitur haec aequatio differentialis:

$$\frac{dx}{\sqrt{(\beta\varepsilon + (\gamma\gamma - \delta\varepsilon - \alpha\beta)xx + \alpha\delta x^4)}} = \frac{dy}{\sqrt{(\alpha\varepsilon + (\gamma\gamma - \delta\varepsilon - \alpha\beta)yy + \beta\delta y^4)}}$$

cuius propterea integralis eſt aequatio aſſumta.

§. 23. Verum haec diſparitas facile tollitur, loco y ponendo $z\sqrt{\frac{\alpha}{\beta}}$, cuius rei ratio ſtatim ex aequatione aſſumta potuiſſet eſſe manifeſta. Sed alia patet via ad formulas diſpares perueniendi, cuius hic exemplum tradidiſſe ſufficiat. Aſſumatur aequatio: $x^4 + 2axxyy + 2bxx = c,$

$= c$, cuius differentiale eſt $dx(x^3 + axyy + bx) + axxydy = 0$, ſeu

$$\frac{dx}{xy} = \frac{-a\,dy}{xx + ayy + b}$$

Iam ex aequatione aſſumta primo determinetur xy per x ſicque fiet $xy = \sqrt{\frac{c - 2bxx - x^4}{2a}}$; tum vero $xx + ayy + b$ per y, at ob $(xx + ayy + b)^2 = c + (ayy + b)^2$, erit

$$xx + ayy + b = \sqrt{(c + (ayy + b)^2)}$$

Quocirca habebitur aequatio differentialis iſta

$$\frac{dx\sqrt{2a}}{\sqrt{(c - 2bxx - x^4)}} = \frac{a\,dy}{\sqrt{(c + bb + 2abyy + aay^4)}}$$

cuius propterea integralis eſt aſſumta ſeu $y = \frac{\sqrt{(c - 2bxx - x^4)}}{x\sqrt{2a}}$

§. 24. Etſi hoc integrale non eſt completum, tamen ex ſuperioribus facile completum reddetur. Ponatur enim:

$$\frac{a\,dy}{\sqrt{(c + bb + 2abyy + aay^4)}} = \frac{a\,dz}{\sqrt{(c + bb + 2abzz + aaz^4)}}$$

ob $f = c + bb$; $g = 2ab$; $h = aa$, erit

$$y = \frac{z\sqrt{(c+bb)(c+bb+2abee+aae^4)} \pm e\sqrt{(c+bb)(c+bb+2abzz+aaz^4)}}{c + bb - aaeezz}$$

hic ergo valor aequalis ſtatuatur ipſi $\frac{\sqrt{(c - 2bxx - x^4)}}{x\sqrt{2a}}$, et aequatio hinc inter x et z reſultans integralis erit completa huius aequationi differentialis

$$\frac{dx\sqrt{2a}}{\sqrt{(c - 2bxx - x^4)}} = \frac{a\,dz}{\sqrt{(c + bb + 2abzz + aaz^4)}}.$$

Quin etiam ex allatis patet, ſi haec bina membra inſuper per numeros rationales quoscunque multiplicentur, quemadmodum integrale completum inueniri oporteat.

§. 25. Verum missa membrorum disparitate formationem parium membrorum generalius concipimus, ponatur ergo:

$$(1)\quad 0 = \alpha + 2\beta(x+y) + \gamma(xx+yy) + 2\delta xy + 2\varepsilon xy(x+y) + \zeta xxyy$$

vnde differentiando obtinetur:

$$dx(\beta + \gamma x + \delta y + 2\varepsilon xy + \varepsilon yy + \zeta xyy) + dy(\beta + \gamma y + \delta x + 2\varepsilon xy + \varepsilon xx + \zeta xxy) = 0$$

ideoque

$$(2)\quad \frac{dy}{\beta + \gamma x + \delta y + 2\varepsilon xy + \varepsilon yy + \zeta xyy} = \frac{-dx}{\beta + \gamma y + \delta x + 2\varepsilon xy + \varepsilon xx + \zeta xxy}$$

Ex resolutione autem aequationis assumtae elicitur.

$$y = \frac{-\beta - \delta x - \varepsilon xx \pm \sqrt{(\beta\beta - \alpha\gamma + 2(\beta\delta - \alpha\varepsilon - \beta\gamma)x + (\delta\delta - \gamma\gamma - \alpha\zeta - 2\beta\varepsilon)xx + 2(\delta\varepsilon - \beta\zeta - \gamma\varepsilon)x^3 + (\varepsilon\varepsilon - \gamma\zeta)x^4)}}{\gamma + 2\varepsilon x + \zeta xx}$$

Ponatur breuitatis gratia

$\beta\beta - \alpha\gamma = A$; $\beta\delta - \alpha\varepsilon - \beta\gamma = B$; $\delta\delta - \gamma\gamma - \alpha\zeta - 2\beta\varepsilon = C$

$\varepsilon\varepsilon - \gamma\zeta = E$ $\delta\varepsilon - \beta\zeta - \gamma\varepsilon = D$;

eritque

$$\beta + \delta x + \varepsilon xx + \gamma y + 2\varepsilon xy + \zeta xxy = \pm\sqrt{(A + 2Bx + Cxx + 2Dx^3 + Ex^4)}$$

$$\beta + \delta y + \varepsilon yy + \gamma x + 2\varepsilon xy + \zeta xyy = \mp\sqrt{(A + 2By + Cyy + 2Dy^3 + Ey^4)}$$

§. 26. Hinc itaque concludimus huius aequationis differentialis:

$$\frac{dx}{\sqrt{(A + 2Bx + Cxx + 2Dx^3 + Ex^4)}} = \frac{dy}{\sqrt{(A + 2By + Cyy + 2Dy^3 + Ey^4)}}$$

aequationem integralem eamque completam esse

$$0 = \alpha + 2\beta(x+y) + \gamma(xx+yy) + 2\delta xy + 2\varepsilon xy(x+y) + \zeta xxyy$$

adhi-

adhibita ſcilicet ſuperiori horum coëfficientium determinatione. Primum autem definiatur β vel ε ex hac aequatione

$$\frac{BB(\varepsilon\varepsilon-E)-DD(\beta\beta-A)}{A\varepsilon\varepsilon-E\beta\beta}+\frac{2AD\varepsilon-2BE\beta}{B\varepsilon-D\beta}=C$$

tum vero erit:

$$\gamma=\frac{A\varepsilon\varepsilon-E\beta\beta}{B\varepsilon-D\beta};\ \alpha=\frac{\beta\beta-A}{\gamma};\ \zeta=\frac{\varepsilon\varepsilon-E}{\gamma}\ \text{et}$$
$$\delta=\frac{B\beta(\varepsilon\varepsilon-E)-D\varepsilon(\beta\beta-A)}{A\varepsilon\varepsilon-E\beta\beta}+\gamma\ \text{ſeu}\ \delta=\gamma+\frac{B+\alpha\varepsilon}{\beta}$$

§. 27. Hinc ergo perſpicuum eſt etiam hanc aequationem differentialem:

$$\frac{dx}{\sqrt{(A+2Dx^3)}}=\frac{dy}{\sqrt{(A+2Dy^3)}}$$

integrari poſſe: nam ob $B=0$, $C=0$ et $E=0$ erit

$$-\frac{DD(\beta\beta-A)}{A\varepsilon\varepsilon}-\frac{2A\varepsilon}{\beta}=0\ \text{ſeu}\ \varepsilon=\sqrt[3]{\frac{DD}{2AA}\beta(A-\beta\beta)}$$

at hinc valores nimis prodeunt complicati. Facilius negotium abſoluetur, reſoluendo valores litterarum euaneſcentium B, C et E; nam $E=0$ dat: $\zeta=\frac{\varepsilon\varepsilon}{\gamma}$; tum $B=0$ dat: $\delta=\gamma+\frac{\alpha\varepsilon}{\beta}$; atque $C=0$ dat $\delta\delta-\gamma\gamma=\alpha\zeta+2\beta\varepsilon=\frac{\alpha\varepsilon\varepsilon}{\gamma}+2\beta\varepsilon=\frac{\alpha^2\varepsilon\varepsilon}{\beta\beta}+\frac{2\alpha\gamma\varepsilon}{\beta}$ cuius factores ſunt $\beta\beta=\alpha\gamma$ et $\alpha\varepsilon\varepsilon+2\beta\gamma\varepsilon=0$. At ſi eſſet $\beta\beta=\alpha\gamma$ foret $A=0$, ſin autem eſſet $\varepsilon=0$ foret et $\zeta=0$ et $D=0$, contra ſcopum. Fieri ergo oportet $\alpha\varepsilon=-2\beta\gamma$; vnde fiet $\alpha=-\frac{2\beta\gamma}{\varepsilon}$; $\delta=-\gamma$; et $\zeta=\frac{\varepsilon\varepsilon}{\gamma}$. Denique fieri debet $\beta\beta+\frac{2\beta\gamma\gamma}{\varepsilon}=A$ et $-2\gamma\varepsilon-\frac{\beta\varepsilon\varepsilon}{\gamma}=D$. Inde fit $\varepsilon=\frac{2\beta\gamma\gamma}{A-\beta\beta}$; et ob $\frac{\gamma D}{\varepsilon}=-(2\gamma\gamma+\beta\varepsilon)$ et $2\gamma\gamma+\beta\varepsilon=\frac{A\varepsilon}{\beta}$, erit $\frac{\gamma D}{\varepsilon}=-\frac{A\varepsilon}{\beta}$; ideoque $\varepsilon\varepsilon=-\frac{\beta\gamma D}{A}$. Ergo $\frac{4\beta\gamma^3}{(A-\beta\beta)^2}+\frac{D}{A}=0$.

 §. 28.

§. 28. Cum autem tantum ratio litterarum A et D in censum veniat, aequatio vltima valori absoluto ipsius A inueniendo inseruit, quem autem nosse non est opus. Manebunt ergo litterae γ et β indeterminatae. Ponatur ergo $\gamma = -Ac$ et $\beta = Dc$, erit $\varepsilon\varepsilon = DDcc$, seu $\varepsilon = Dc$, hincque $\delta = Ac$; $\zeta = -\frac{DDc}{A}$; et $\alpha = 2Ac$. Quare huius aequationis differentialis:

$$\frac{dx}{\sqrt{(A + 2Dx^3)}} = \frac{dy}{\sqrt{(A + 2Dy^3)}}$$

integrale est.

$$0 = 2A + 2D(x+y) - A(xx+yy) + 2Axy + 2Dxy(x+y) - \frac{DD}{A}xxyy$$

Hoc autem integrale non est completum, tale autem reddetur ponendo $\gamma = -A$ et $\beta = Dcc$, vnde fit $\varepsilon\varepsilon = DDcc$ et $\varepsilon = Dc$; porro erit $\delta = A$; $\zeta = -\frac{DDcc}{A}$; $\alpha = 2Ac$; ita vt integrale completum fit:

$$0 = 2Ac + 2Dcc(x+y) - A(xx+yy) + 2Axy + 2Dcxy(x+y) - \frac{DDcc}{A}xxyy$$

vbi c est constans ab arbitrio pendens, vnde fit:

$$y = \frac{Dcc + Ax + Dcxx \pm \sqrt{c(2A + \frac{DD}{A}c^3)(A + 2Dx^3)}}{A - 2Dcx + \frac{DDcc}{A}xx}$$

§. 29. Hic casus notari meretur, quo $A = 1$ et $D = \frac{1}{2}$, vt habeatur haec aequatio differentialis

$$\frac{dx}{\sqrt{(1 + x^3)}} = \frac{dy}{\sqrt{(1 + y^3)}}$$

vbi ad fractiones tollendas loco c scribatur $2c$ eritque integrale completum:

$$0 = 4c + 4cc(x+y) - xx - yy + 2xy + 2cxy(x+y) - ccxxyy$$

$$\text{seu } y = \frac{2cc + x + cxx \pm 2\sqrt{c(1+c^3)(1+x^3)}}{1 - 2cx + ccxx}$$

integra-

Integralia ergo particularia erunt

I. si $c = 0$; $y = x$;

II. si $c = \infty$; $y = \frac{2 \pm 2\sqrt{(1+x^3)}}{xx}$

III. si $c = -1$; $y = \frac{2+2x-xx}{1+2x+xx} = \frac{2-x}{1+x}$.

§. 30. Ex eodem principio si in §. 29. loco litterarum A, B, C, D, E, eaedem per quantitatem quampiam p multiplicentur, nihilo minus aequatio differentialis erit

$$\frac{dx}{\sqrt{(A+2Bx+Cxx+2Dx^3+Ex^4)}} = \frac{dy}{\sqrt{(A+2By+Cyy+2Dy^3+Ey^4)}}$$

inuenieturque

$$p = \frac{BB\varepsilon\varepsilon - DD\beta\beta}{BBE - ADD} + 2\frac{(AD\varepsilon - BE\beta)(A\varepsilon\varepsilon - E\beta\beta)}{(B\varepsilon - D\beta)(BBE - ADD)} - \frac{C(A\varepsilon\varepsilon - E\beta\beta)}{BBE - ADD}$$

tum erit $\gamma = \frac{A\varepsilon\varepsilon - E\beta\beta}{B\varepsilon - D\beta}$; $\alpha = \frac{\beta\beta - Ap}{\gamma}$; $\zeta = \frac{\varepsilon\varepsilon - Ep}{\gamma}$ atque $\delta = \gamma + \frac{\alpha\varepsilon + Bp}{\beta}$: ita vt litterae β et ε maneant indeterminatae, fietque propterea aequatio integralis completa:

$$0 = \alpha + 2\beta(x+y) + \gamma(xx+yy) + 2\delta xy + 2\varepsilon xy(x+y) + \zeta xxyy$$

vnde fit:

$$y = \frac{-\beta - \delta x - \varepsilon xx \pm \sqrt{p}(A+2Bx+Cxx+2Dx^3+Ex^4)}{\gamma + 2\varepsilon x + \zeta xx}$$

§. 31. Notandum denique est, non solum hanc aequationem differentialem, cuius integrale completum modo exhibui, sed etiam hanc multo latius patentem

$$\frac{m\,dx}{\sqrt{(A+2Bx+Cxx+2Dx^3+Ex^4)}} = \frac{n\,dy}{\sqrt{(A+2By+Cyy+2Dy^3+Ey^4)}}$$

semper algebraice et quidem complete integrari posse, dummodo coëfficientium m et n ratio fuerit rationalis: haec enim integratio simili modo instituitur, quo supra vlus sum ad aequationem, quae mihi hic praecipue erat proposita, integrandam. Methodus autem, cuius

 hic

hic ſpecimina attuli, ita mihi videtur comparata, vt indolem eius diligentius excolendo, ad inſignes vſus ap:a reddi queat, vnde haud contemnenda commoda in Analyſin ſint redundatura.

§. 32. Hic autem obſeruo, formulam §. 28 aſſumtam latius extendendo, eiusmodi differentialia inter ſe comparari poſſe, quae ſint diſparia, atque adeo exemplum diſparitatis §. 26. allatum hoc modo obtineri poſſe; ita vt omnia, quae hactenus ſunt tradita, in hac generali inueſtigatione contineantur. Fingatur ſcilicet haec aequatio integralis:

$$(1)\ldots \alpha xxyy + 2\beta xxy + 2\gamma xyy + \delta xx + \varepsilon yy + 2\zeta xy + 2\eta x + 2\theta y + \kappa = 0$$

ex qua fit

$$(2)\ldots y = \frac{-\beta xx - \zeta x - \theta + \surd((\beta xx + \zeta x - \theta)^2 - (\alpha xx + 2\gamma x + \varepsilon)(\delta xx + 2\eta x + \kappa))}{\alpha xx + 2\gamma x + \varepsilon}$$

$$(3)\ldots x = -\frac{\gamma yy - \zeta y - \eta - \surd((\gamma yy + \zeta y + \eta)^2 - (\alpha yy + 2\beta y + \delta)(\varepsilon yy + 2\theta \eta + \kappa))}{\alpha yy + 2\beta y + \delta}$$

Ponatur iam breuitatis gratia:

$App = \beta\beta - \alpha\delta$	$\mathfrak{A}qq = \gamma\gamma - \alpha\varepsilon$
$2Bpp = 2\beta\zeta - 2\alpha\eta - 2\gamma\delta$	$2\mathfrak{B}qq = 2\gamma\zeta - 2\alpha\theta - 2\beta\varepsilon$
$Cpp = \zeta\zeta + 2\beta\theta - \alpha\kappa - \delta\varepsilon - 4\gamma\eta$	$\mathfrak{C}qq = \zeta\zeta + 2\gamma\eta - \alpha\kappa - \delta\varepsilon - 4\beta\theta$
$2Dpp = 2\zeta\theta - 2\gamma\kappa - 2\varepsilon\eta$	$2\mathfrak{D}qq = 2\zeta\eta - 2\beta\kappa - 2\delta\theta$
$Epp = \theta\theta - \varepsilon\kappa$	$\mathfrak{E}qq = \eta\eta - \delta\kappa$

eritque:

$$(4)\ldots p\surd(Ax^4 + 2Bx^3 + Cxx + 2Dx + E) = \alpha xxy + 2\gamma xy + \varepsilon y + \beta xx + \zeta x + \theta$$

$$(5)\ldots -q\surd(\mathfrak{A}y^4 + 2\mathfrak{B}y^3 + \mathfrak{C}yy + 2\mathfrak{D}y + \mathfrak{E}) = \alpha xyy + 2\beta xy + \delta x + \gamma yy + \zeta y + \eta$$

§. 33.

§. 33. At ſi aequatio integralis aſſumta differentietur, fiet

$$(6)\ldots dx(\alpha xyy+2\beta xy+\gamma yy+\delta x+\zeta y+\eta)+dy(\alpha xxy+\beta xx+2\gamma xy+\varepsilon y+\zeta x+\theta)=0$$

vnde ſi iſtorum factorum valores (4) et (5) reperti ſubſtituantur, orietur iſta aequatio differentialis:

$$(7)\ldots \frac{q\,dx}{\sqrt{(Ax^4+2Bx^3+Cxx+2Dx+E)}}=\frac{p\,dy}{\sqrt{(\mathfrak{A}y^4+2\mathfrak{B}y^3+\mathfrak{C}yy+2\mathfrak{D}y+\mathfrak{E})}}$$

cuius propterea integralis eſt aequatio aſſumta (1).
Cum autem ſupra habeantur 10 aequationes, coëfficientium autem $\alpha, \beta, \gamma, \delta$, etc. numerus ſit 9, quorum vnus pro lubitu aſſumi poteſt, octo remanebunt litterae determinandae. Porro autem inſuper definiendae accedunt binae litterae p et q, ita vt nunc decem quantitates adſint incognitae; ex quo coëfficientes vtriusque formulae A, B, C, D, E et $\mathfrak{A}, \mathfrak{B}, \mathfrak{C}, \mathfrak{D}, \mathfrak{E}$ videntur pro lubitu aſſumi poſſe. Verum perſpicuum eſt, cum alteri iam fuerint ad libitum aſſumti, alteros non omnino ab arbitrio noſtro pendere, alias enim quaeuis formula ad algebraicam reduci poſſet.

§. 34. Hinc autem aliae datae formulae transmutationes non inelegantes obtineri poſſunt, ſi loco y alii valores ſubſtituantur. Veluti ſi ponatur $\mathfrak{C}=0$, ſeu $\eta\eta=\delta x$, ſtatuaturque $y=zz$ ſequens prodibit aequatio differentialis.

$$(8)\ldots \frac{q\,dx}{\sqrt{(Ax^4+2Bx^3+Cxx+2Dx+E)}}=\frac{2p\,dz}{\sqrt{(\mathfrak{A}z^6+2\mathfrak{B}z^4+\mathfrak{C}z^2+2\mathfrak{D})}}$$

cuius propterea integralis eſt aequatio aſſumta, ſi ponatur $y=zz$, ſtatuaturque $\eta\eta=\delta x$, ac reliquae litterae rite deter-

determinentur. Integrale etiam completum nulla difficultate reperietur, nam etiamsi fortasse integrale inuentum nouam non inuoluat constantem, ponatur

$$\frac{q\,dx}{\sqrt{(Ax^4 + 2Bx^3 + Cxx + 2Dx + E)}} = \frac{q\,du}{\sqrt{(Au^4 + 2Bu^3 + Cuu + 2Du + E)}}$$

et huius aequationis integrale completum ex antecedentibus assignare licebit; atque hinc integrale quoque completum aequationis ex formulis disparibus constantis colligetur.

§. 35. Quemadmodum huius aequationis differentialis, vt a simplicissimis incipiam:

$$\frac{dx}{\sqrt{(f + gx)}} = \frac{dy}{\sqrt{(f + gy)}}$$

integrale completum est:

$$gg(xx + yy) - 2ggxy - 2ccg(x + y) + c^4 - 4ccf = 0$$

Deinde vero huius aequationis differentialis

$$\frac{dx}{\sqrt{(f + gxx)}} = \frac{dy}{\sqrt{(f + gyy)}}$$

integrale completum est:

$$xx + yy - 2xy\sqrt{(1 + fgcc)} - ccff = 0$$

Tertio vero huius aequationis differentialis

$$\frac{dx}{\sqrt{(f + gx^3)}} = \frac{dy}{\sqrt{(f + gy^3)}}$$

integrale completum est

$$f(xx + yy) + \frac{ggcc}{4f}xxyy - gcxy(x + y) - 2fxy - gcc(x + y) - 2fc = 0$$

Quarto porro huius aequationis differentialis

$$\frac{dx}{\sqrt{(f + gx^4)}} = \frac{dy}{\sqrt{(f + gy^4)}}$$

integrale completum repertum est

$$f(xx + yy) - fcc - gccxxyy - 2xy\sqrt{f(f + gc^4)} = 0$$

Ita

Ita etiam integrale completum huius aequationis

$$\frac{dx}{\sqrt{(f+gx^6)}} = \frac{dy}{\sqrt{(f+gy^6)}}$$

reperiri poterit:

§. 36. Determinentur primo in §. 33. valores, ita vt prodeat haec aequatio

$$\frac{dx}{\sqrt{(fx+gx^4)}} = \frac{dy}{\sqrt{(fy+gy^4)}}$$

cuius integralis completa reperitur:

$$gg(xx+yy) - 4ggc\,xxyy - 4fgccxy(x+y) - 2gg\,xy - 2fgc(x+y) + ffcc = 0$$

Ponatur nunc $x = tt$ et $y = uu$, vt prodeat haec aequatio differentialis

$$\frac{dt}{\sqrt{(f+gt^6)}} = \frac{du}{\sqrt{(f+gu^6)}}$$

cuius propterea integralis completa erit

$$gg(t^4+u^4) - 4ggc\,t^4u^4 - 4fg\,cc\,tt\,uu(tt+uu) - 2gg\,tt\,uu - 2fgc(tt+uu) + ffcc = 0$$

vnde notari meretur casus ex hypothesi $c = \infty$ resultans, qui dat $4g\,tt\,uu(tt+uu) = f$.