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ergetic graphs emerged as an important area of research. We note that graphs for which the energy is greater than $2(n-1)$ are called hyperenergetic graphs. To learn some more results on energy of graphs one may refer ([63], [4], [24], [50],[27]).

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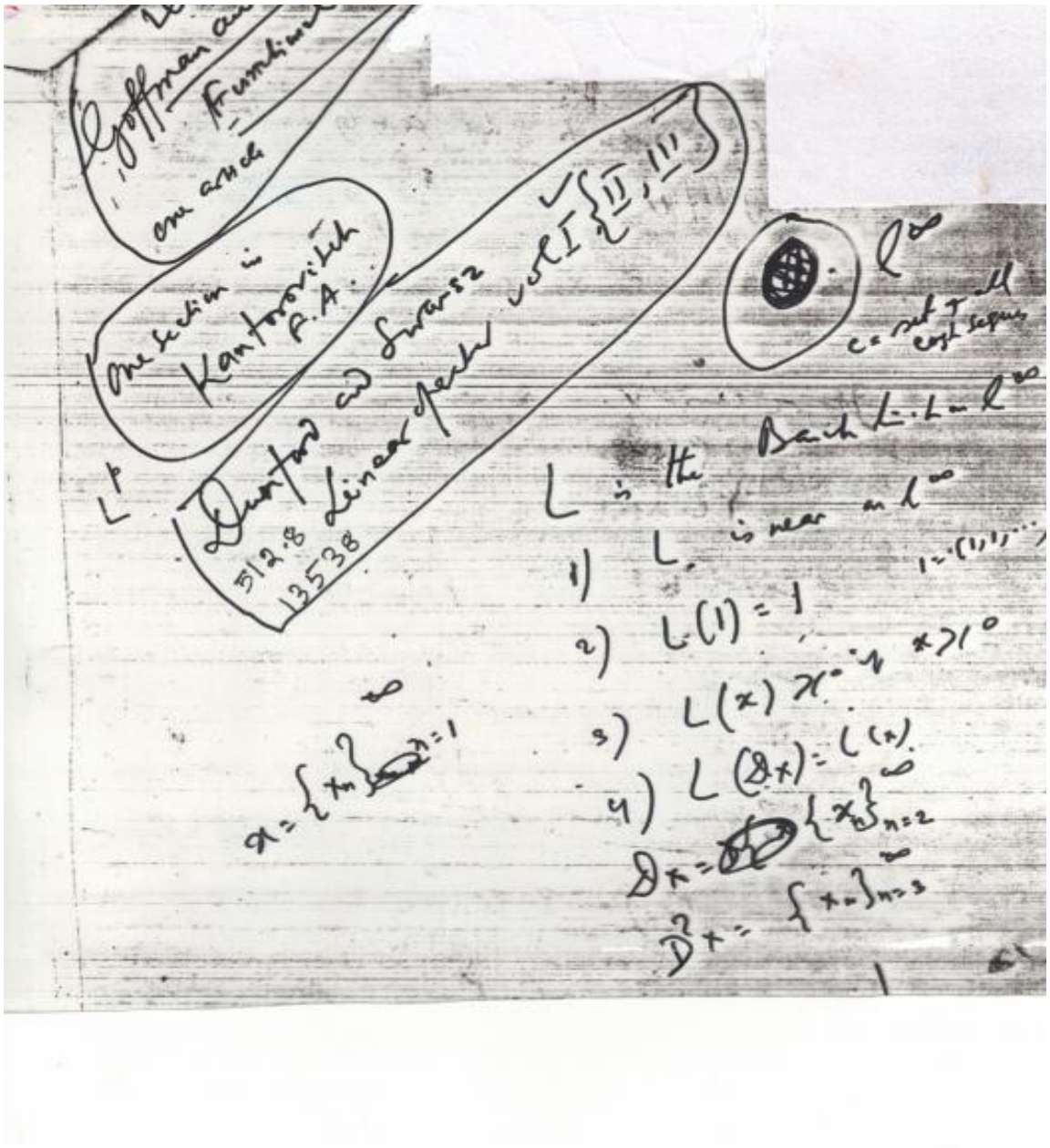
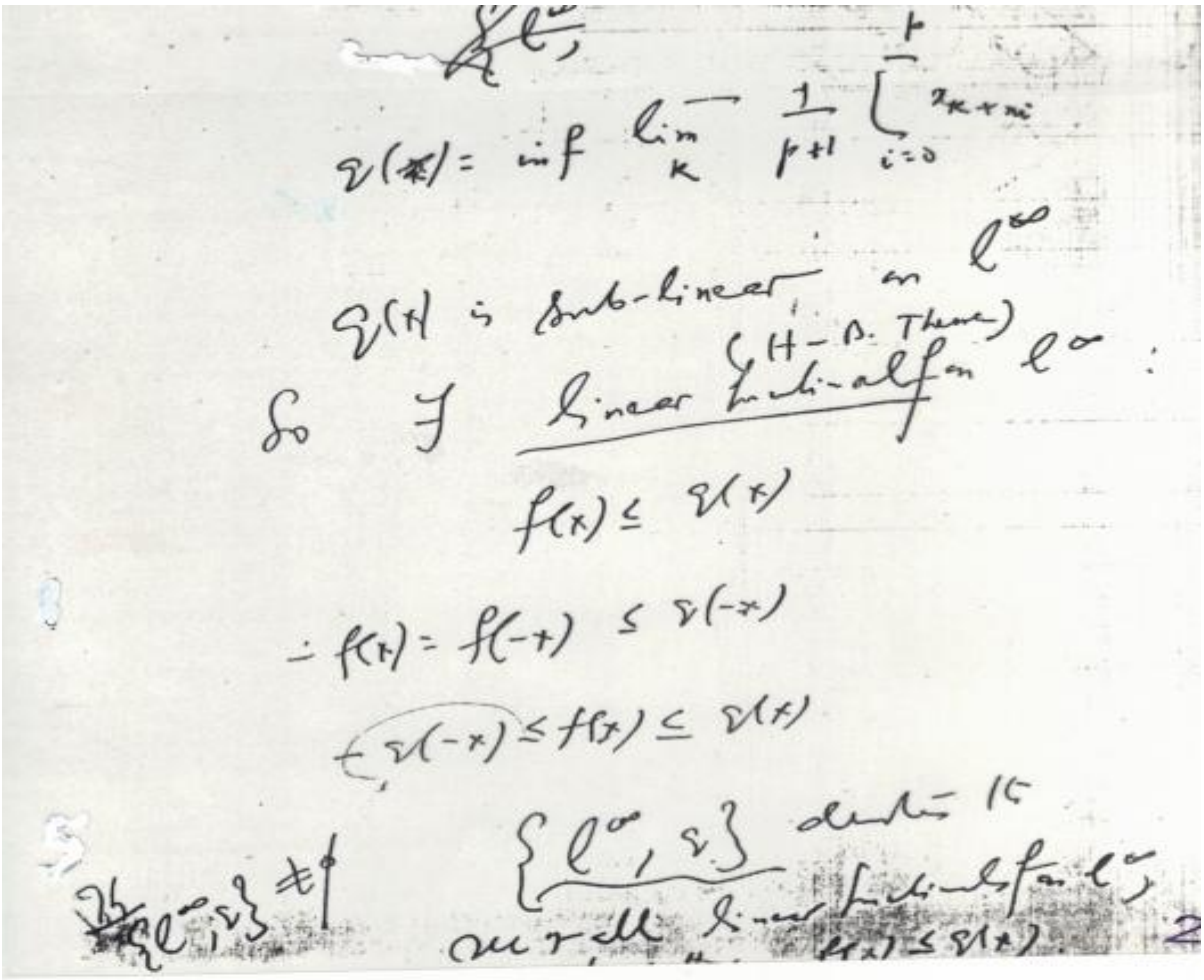
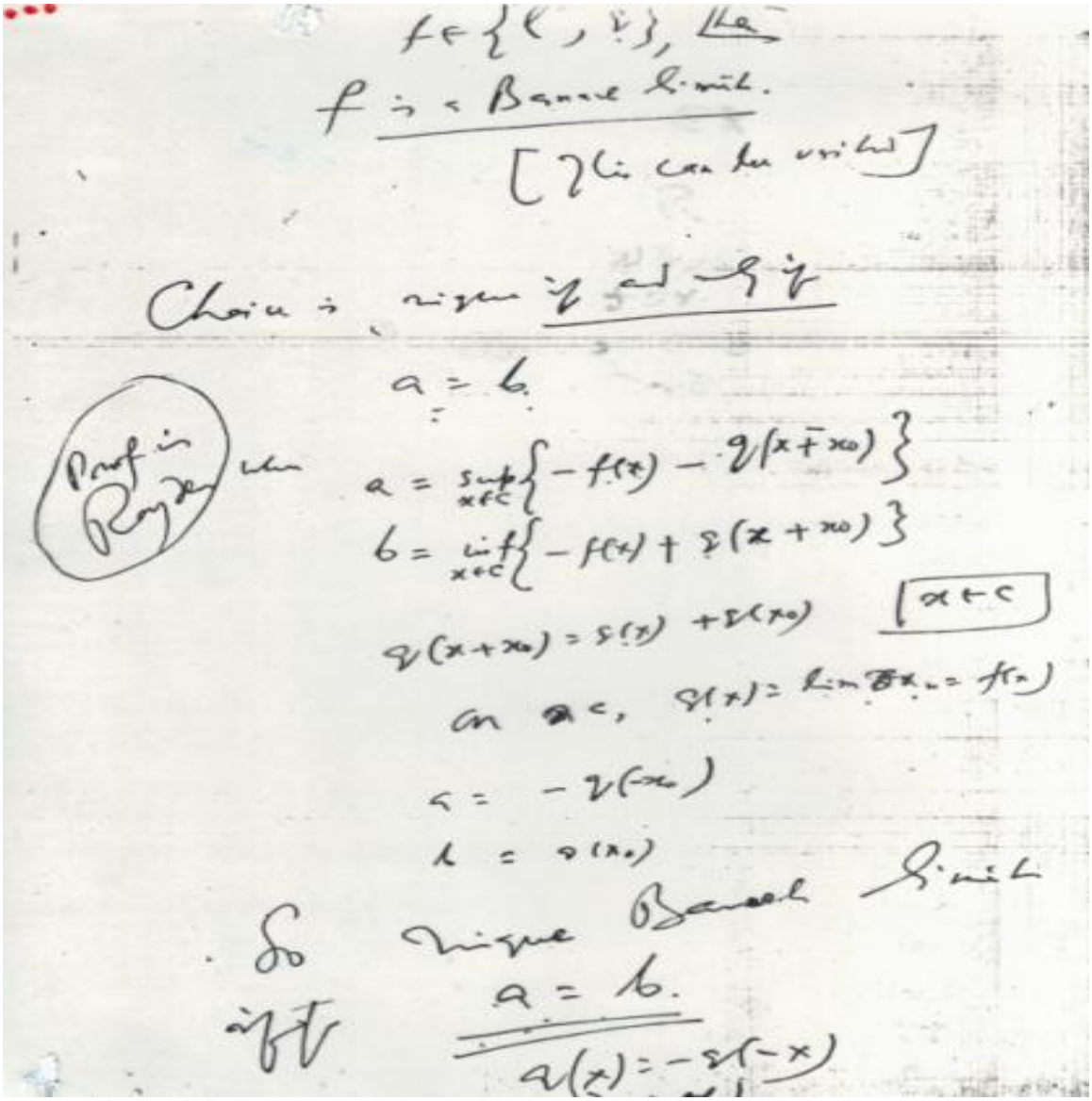
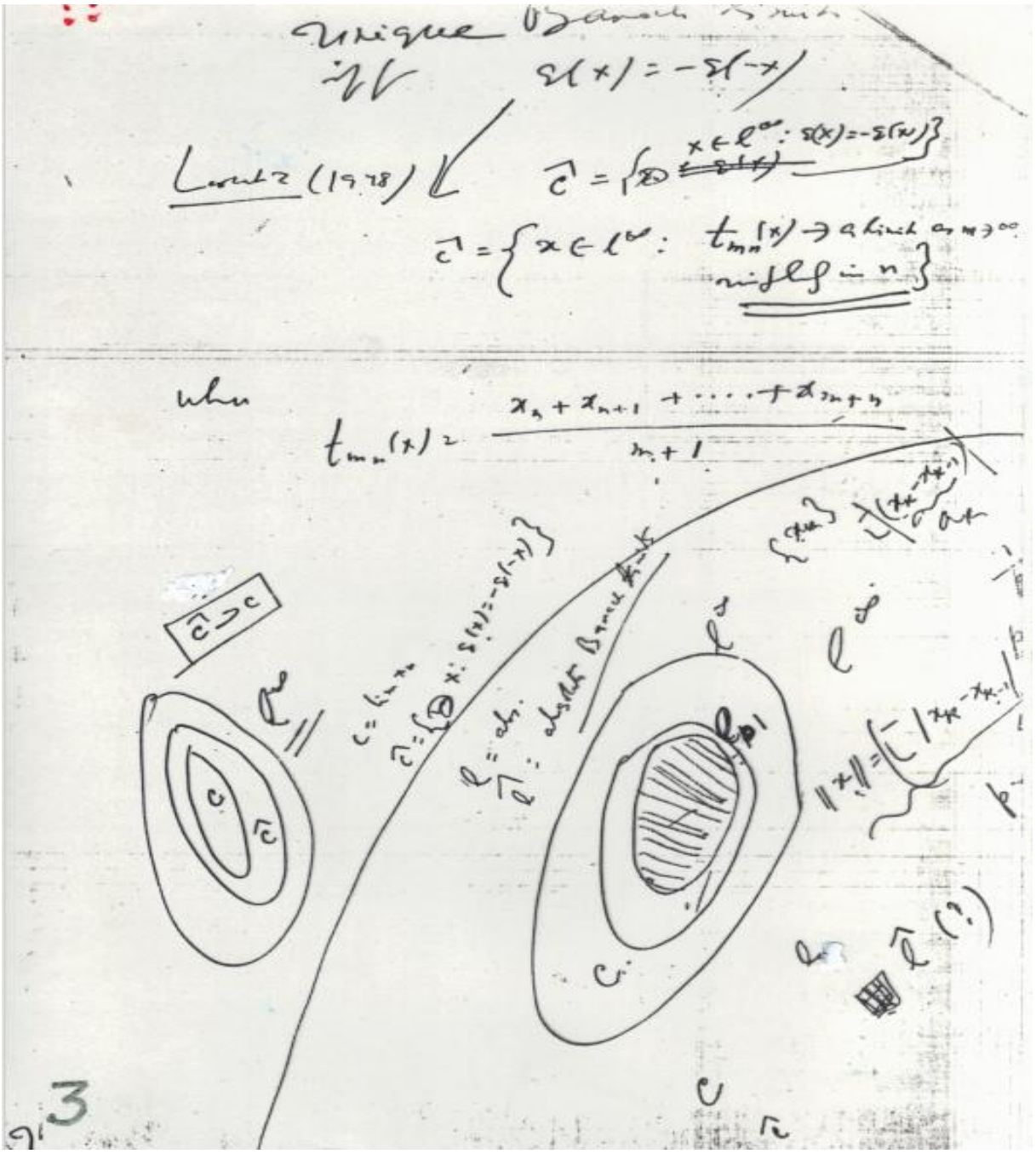
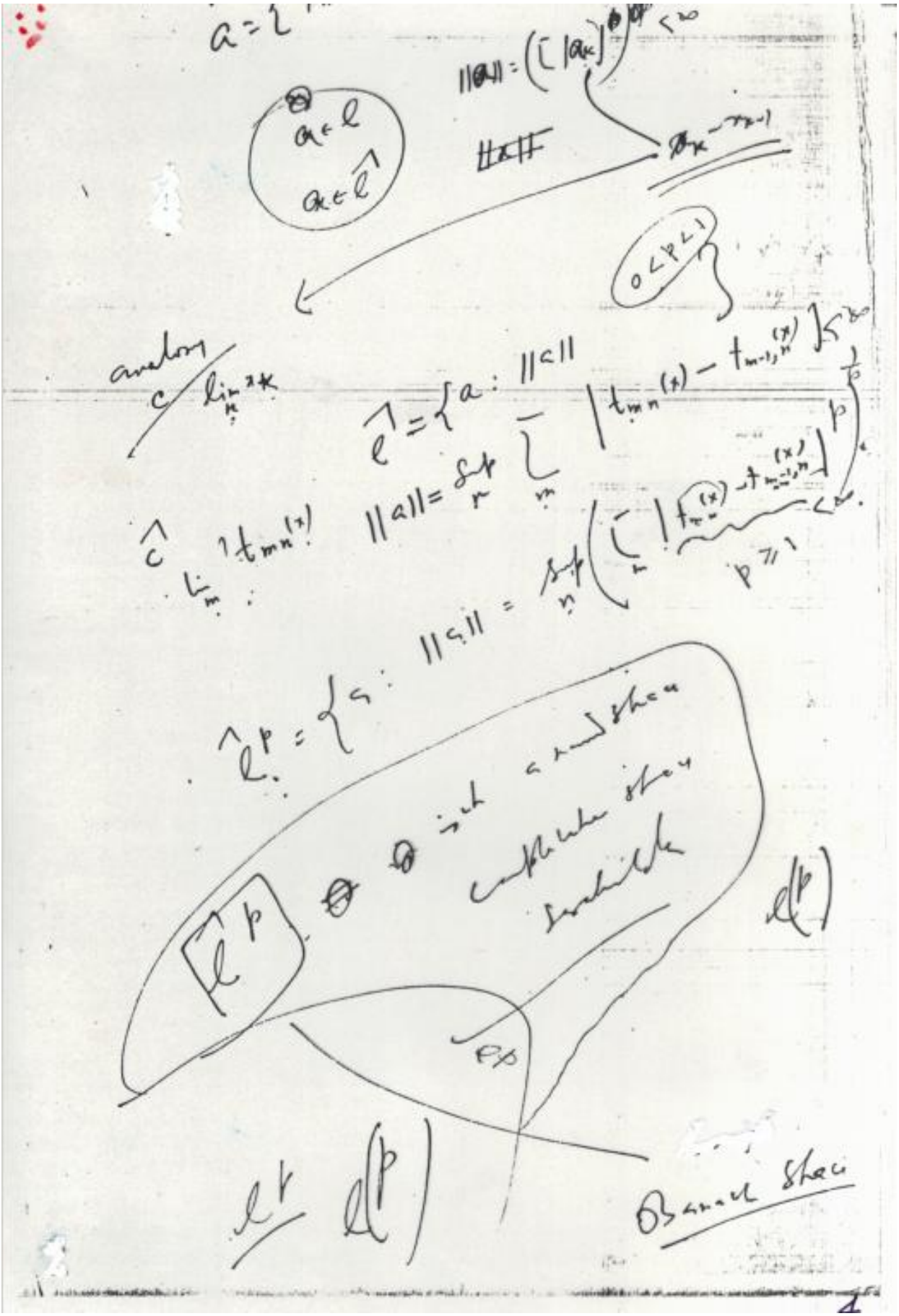
The Problem Suggested by Prof.G Das to me during my first visit (July 1972)


Kantorovitch
P.A.
Quantor and Swarcz
512.8
13538
Linear spaces
L is the Banach L-L on l∞
1) L is near on l∞
2) L(1) = 1
3) L(x) ≥ 0 if x ≥ 0
4) L(Dx) = L(x)
Dx = {x_n}_{n=2}^∞
D²x = {x_n}_{n=3}^∞


$p(x) = \inf \lim_k \frac{1}{k+1} \sum_{i=0}^{k} x_{k+i}$
$p(x)$ is sub-linear on l^∞
(H-B. Theorem)
So $\exists$ linear functional f on l^∞ :
$f(x) \le p(x)$
$\therefore f(x) = f(-x) \le p(-x)$
$-p(-x) \le f(x) \le p(x)$
$\{l^\infty, \|\cdot\|\}$ dual is l^1
$\{l^\infty, \|\cdot\|\} \neq l^1$


f ∈ {ℓ, ν}, La
f is a Banach limit.
[Li can be written]
Claim : given ℓ and g ∈
a = b.
Proof in Rayden
a = sup_{x∈C} { − f(x) − g(x + x0) }
b = inf_{x∈C} { − f(x) + g(x + x0) }
g(x + x0) = g(x) + g(x0)
x ∈ C
on a c, g(x) = lim x_n = f(x)
c = − g(x0)
l = g(x0)
So Unique Banach limit
iff a = b.
g(x) = − g(−x)


Unique
Lorentz (1948)
when


$a = l^p$
$\|a\| = \left(\sum |a_k|^p\right)^{1/p} < \infty$
$a_k \in l$
$a_k \in \hat{l}$
$0 < p < 1$
analogy
$\hat{l} = \{a : \|a\|$
$\|a\| = \sup_n \sum_m \left| t_{mn}(x) - t_{m-1,n}(x) \right|^p \Big]^{1/p}$
$\hat{c}$
$\lim_n t_{mn}(x)$
$\lim_m$
$\hat{l}^p = \{a : \|a\| =$
$\hat{l}^p$
l^p
$d(p)$
l^p
$d(p)$
B-space

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A Brief review of Fractional calculus

Sudarsan Nanda

Dedicated to the memory of Prof. Gokulananda Das

This note presents a brief review of fractional calculus. it is not a complete review. Leibnitz, for the first time used the notation $\frac{d^n y}{dx^n}$ for a real function y of x, n being a positive integer. During 1695, L' Hospital asked Leibnitz [14] what will happen if n=1/2. This led to the question whether $\frac{d^n y}{dx^n}$ can be given a meaning when n is a fractional number.

1. Initial developments

During 1819 AD Lacroix [13] stated a formula for nth derivative of $y = x^m$ when m and n are positive integers, which is as follows:

$$\frac{d^n y}{dx^n} = \frac{m!}{(m-n)!} x^{m-n}, \qquad m \geq n \qquad (1)$$

If we write this formula in term of gamma function we obtain that

$$\frac{d^n y}{dx^n} = \frac{\Gamma(\mathrm{m}+1)}{\Gamma(m-n+1)!} x^{m-n}, m \geq n \qquad (2)$$

This clue motivated to define the fractional derivative of $y = x^m$, when n is a fraction, say α. Then

$$\frac{d^\alpha y}{dx^\alpha} = \frac{d^\alpha x^m}{dx^\alpha} = D^\alpha x^m = \frac{\Gamma(\mathrm{m}+1)}{\Gamma(m-\alpha+1)} x^{m-\alpha} \qquad (3)$$

In particular, if m=1, i.e, y=x and $\alpha = 1/2$, then we have

$$\frac{d^{\frac{1}{2}} y}{dx^{\frac{1}{2}}} = 2\sqrt{\frac{x}{\pi}}$$

Now,

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$$\frac{dy}{dx} = \frac{d^{\frac{1}{2}}}{dx^{\frac{1}{2}}}\left(\frac{d^{\frac{1}{2}}x}{dx^{\frac{1}{2}}}\right) = \frac{d^{\frac{1}{2}}}{dx^{\frac{1}{2}}}\left(2\sqrt{\frac{x}{\pi}}\right)$$

$$= 2\pi^{-\frac{1}{2}}\frac{\Gamma(\frac{1}{2}+1)}{\Gamma\left(\frac{1}{2}-\frac{1}{2}+1\right)}x^{\frac{1}{2}-\frac{1}{2}}$$

$$= 1.$$

As another example if m=5, that is if $y = x^5$ and α is a fraction, then

$$\frac{d^\alpha y}{dx^\alpha} = \frac{\Gamma(6)}{\Gamma(6-\alpha)}x^{5-\alpha}$$

During 1822 AD, Fourier [10] defined the fractional operators in terms of integral representation of arbitrary real function $y = f(x)$ in the following way

$$f(x) = \frac{1}{2\pi}\int_{-\infty}^{\infty} f(\alpha)d\alpha \int_{-\infty}^{\infty} \cos p(x-\alpha)\, dp \qquad (4)$$

If $\alpha = n$ (an integer), then we have

$$\frac{d^n}{dx^n}\cos p(x-\alpha) = p^n \cos[p(x-\alpha) + n\pi/2]$$

The generalized formula of Fourier is as follows:

$$\frac{d^\mu}{dx^\mu}f(x) = \frac{1}{2\pi}\int_{-\infty}^{\infty} f(\alpha)d\alpha \int_{-\infty}^{\infty} p^\mu \cos[p(x-\alpha) + n\pi/2]\, dp. \qquad (5)$$

2. **Contributions of Abel and Liouville:**

During 1823 AD , Abel used fractional calculus . His integral equation is

$$k = \int_0^x (x-t)^{-1/2} f(t)dt \qquad (6)$$

He obtained that

$$\frac{d^{\frac{1}{2}}k}{dx^{\frac{1}{2}}} = \sqrt{\pi} f(x). \qquad (7)$$

During 1832 AD Liouville [15] extended the arbitrary derivative of a function f(x) that can be expressed in a series as

$$f(x) = \sum_{n=0}^{\infty} c_n e^{a_n x}, \quad Rel\,(a_n) > 0, \qquad (8)$$

$$D^{\alpha} f(x) = \sum_{n=0}^{\infty} c_n (a_n)^{\alpha} e^{a_n x}. \qquad (9)$$

This is known as Liouville's first formula for fractional calculus, where α is any real or complex number.

His second definition is

$$I = \int_0^{\infty} u^{a-1} e^{-xu}\, du, a > 0, x > 0 \qquad (10)$$

By the change of variable, $xu = t$,

$$I = x^{-a}\Gamma(a), \qquad (11)$$

$$x^{-a} = \frac{1}{\Gamma(a)}.$$

Then

$$D^{\alpha} x^{-a} = \frac{1}{\Gamma(a)} (-1)^{\alpha} \int_0^{\infty} u^{a+\alpha-1} e^{-xu}\, du \qquad (12)$$

Thus

$$D^{\alpha}x^{-a} = \frac{(-1)^{\alpha}\Gamma(a+\alpha)}{\Gamma(a)}x^{-(a+\alpha)} \qquad (13)$$

3. **Controversy**

One definition was proposed by Lacroix [13] and another by Liouville [15]. Peacock [18] supported Lacroix [13] version while Kelland [12] supported Liouville's definition. In the year 1848 AD W. Center [9] observed that the derivative of a constant is not zero according to the definition of Lacroix [13].

He took $y = 1 = x^0$ and found $\frac{d^{\frac{1}{2}}x^0}{dx^{\frac{1}{2}}}$ by putting m=0 and $n = \frac{1}{2}$ to get

$\frac{d^{\frac{1}{2}}x^0}{dx^{\frac{1}{2}}} = \frac{1}{\sqrt{\pi x}}$ as the result. Ofcoursr Lacroix [13] assumed that $m \geq n$, but Center took $m = 0$ and $n = \frac{1}{2}$ which means $n > m$.

But Center [9] proved that the fractional derivative of unity is zero by Liouville's second definition which is given by

$$-\infty D^{\alpha}f(x) = \frac{1}{\Gamma(a)}\int_{-c}^{x}(x-t)^{\alpha-1}f(t)dt, \qquad Rel(\alpha) > 0. \qquad (14)$$

4. **Further work**

Euler, Lagrange, Laplace, Riemann, subsequently, Bohr, Riesz, Fourier, Liouville, Hardy and Littlewood, Bosanquet etc. did some works in this direction.

Bosanquet [7] proved the following theorem

For some fixed $b \geq -\infty$ and for $\alpha > 0, \beta > 0$,

$$\phi_{\alpha+\beta}(t) = \frac{1}{\Gamma(\alpha+\beta)} \int_b^t (t-u)^{\alpha+\beta-1} \phi(u) du,$$

Exists as a general Denjoy integral, then $\phi_\alpha(u)$ exists in the Denjoy sense for almost all u in (b,t) and

$$\phi_{\alpha+\beta}(t) = \frac{1}{\Gamma(\beta)} \int_b^t (t-u)^{\beta-1} \phi_\alpha(u) du.$$

The case $b = -\infty$ gives a consistency theorem for the Weyl fractional integral.

5. Conclusion

Initially, the concept of fractional calculus was developed as an academic and logical interest after L Hospital asked the question to Leibnitz the meaning of $\frac{d^n y}{dx^n}$ when $n = \frac{1}{2}$. Later there were a large number of papers dealing with the topic till the present time. We are not mentioning the recent development here particularly developments during twentieth and twenty-first century. After the subject grew up it became very much useful in applications in the problems arising in nature. Therefore, during the present days there are more papers and patents produced by Scientists and Engineers than by Mathematicians.

The concept like fractional calculus is intimately connected with and related to fractal theory, fuzzy logic, optimization, science, engineering and in many other areas.

One single equation $F = mx^\alpha$ gives the laws of equation such as

$F = mx, F = m\dot{x}$, $F = m\ddot{x}$ and many more Laws for all values of α including any real and complex number. For applications and theory besides many more results one can see the works listed in (1-5,6,8,11,16-24).

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A BRIEF REVIEW OF FERMAT'S LAST THEOREM

Sudarsan Nanda*

Dedicated to the memory of Prof. Gokulananda Das

In the 3rd Century AD the famous Greece mathematician Diophantus thought of the equation, $x^n + y^n = z^n$, where n is a positive integer and this was later known as the Diophantine equation. Along with his discoveries, Diophantus mentioned about this equation in his book 'Arithmetica' and his famous book was translated into English by C.G. Bachet.

Pierre de Fermat (1601-1665) was born in France in the year 1601. He was basically a lawyer and a parliamentarian and his hobby was Mathematics, in particular, Number Theory.

Fermat's Last Theorem states that:

If n > 2 then $\boldsymbol{x^n + y^n = z^n}$ cannot have integer solutions.

In the year 1637, while Fermat was reading the English translation of 'Arithmetica' he thought of the theorem. He claimed that he knew the proof, but remarked that the space in the margin of the book was very much insufficient to mention it. He gave some hints in his notebook, but it was not legible.

Attempts for Proof

After Fermat, many noted mathematicians made attempts to prove the result, many did not show interest in it. Fermat himself supplied the proof for n=4. Euler (1707-1783) gave the proof for n=3. It may be noted that if the result is true for n=m, then it is true for n=ml, l=1,2… Since

$a^{ml} + b^{ml} = c^{ml}$ is $(a^l)^m + (b^l)^m = (c^l)^m$

Therefore Fermat's last Theorem is true for, n = 4, 8, 12, 16, 20, 24…. and n = 3, 6,9,12,15,18, …

In the year 1816, Paris Academy of Sciences declared a prize for one who could prove the theorem within the year 1818!

Gauss (1777-1855) was asked to make an attempt and he refused to do so. He remarked that he could suggest several conjectures, which would be difficult to prove or disprove. Dirichlet (1805-1859) established the result for n = 5 and n = 14. Thus the theorem is also true for n = 5, 10, 15, 20,… and n = 14, 28, 42, 56, … Gradually time passed and nineteenth century was over. On 27th June, 1908 a prize called Wolfskehl Prize was declared for proving Fermat's Last Theorem. The money was kept in a trust in Gottingen Royal Academy and the time limit was 13th September 2007.

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In 1920 Hilbert (1862- 1943) was approached and he said he had no time for possible un success. Hardy (1877- 1947), Ramanujan (1887-1920), Cauchy (1789-1857), Fourier(1768-1830), Jacobi (1804-1851), Weierstrass (1815-1896), Abel (1802-1829), Riemann (1826-1866), Dedekind(1831-1916), Cantor(1845-1918) and many other eminent mathematicians did not show interest. On the other hand several people made attempts and sent their proofs to the Royal Academy or to several notable mathematicians. The number of people trying to prove the theorem was so high that it was impossible for mathematicians to check these.

E Temple Bell (1883-1960) in his article entitled 'The Queen of Mathematics' mentioned that no one should send the proof to him for checking. Landau had printed post cards. Whenever he was receiving manuscripts containing the proofs, he used to give them to his Ph.D. students for checking and the answers were as follows:

Your MS p. _____ , L _____ contains mistakes.

F. Schlichting (Professor at the University of Gottingen) observed that people who were not much reputed in their own fields showed more interest with ultimate unsuccess.

While trying to prove FLT, German mathematician Kummer discovered 'Theory of Ideals' and gave some ideas for the proof in the year 1943. He proved that the theorem is true for all but three values of n below 100 (37, 59, 67). While trying to prove, Euler made the following conjecture:

If r, n are positive integers and r < n then for any positive integer a_1, a_2, a_3, …,a_r, c,

$a_1^n + a_2^n + a_3^n + \ldots + a_r^n = c^n$ is not true.

It may be noted that Euler's conjecture implies FLT. But Euler's conjecture is false.

For example,

$27^5 + 84^5 + 110^5 + 133^5 = 144^5$ and this appears in Lander and Perkin, Math Comp 21 (1967) 101-103.

Japanese mathematician Taniyama made a conjecture known as Taniyama's conjecture and in the year 1985 K. Ribet showed that Taniyama's conjecture implies Fermat's last Theorem. On June 23, 1993 Professor Andrew J. Wiles, a 40 years old Professor, Princeton University declared at the Newton Institute, Cambridge that he has proved the theorem and he came forward with a 200 page proof. Like many others Wiles attempted Taniyama's conjecture and according to him he was successful. He also demonstrated Fermat's Last Theorem to be true for all n up to 1, 25000. Probably the result is also known to be valid for all values of n up to 4,000,000.

Wiles in 1993 prepared a paper solving the problem and sent his paper to 'Inventiones Mathematicae' for favour of publication. Professor Barry Mazur of Harvard University, the editor of the journal sent the paper to six reviewers for scrutiny. Reviewers found some knots and Wiles had been able to untie all of them, except one, and Wiles hope was that he will be able to justify this in near future.

The serious gap that Wiles' paper had, was the construction of a Euler system. After trying unsuccessfully to repair that construction, Wiles went back to a different approach, which he tried earlier. Wiles now wrote a paper jointly with Richard Taylor in the year 1995. This new approach turns

out to be significantly simpler and shorter than the original one. The paper has now been published and the result seems to be valid, thus the problem appears to be solved.

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