# Chapter 6: Integration Techniques

## 6.1: "The Amazing" Integration by Parts

We don't know how to integrate this: $\int_a^b f(x)\, g(x)\, dx$.

Let's find out how...

Let $f(x)$ and $g(x)$ be differentiable functions

Recall the product rule:

$$\frac{d}{dx}[f(x)\,g(x)] = \frac{d}{dx}[f(x)]\,g(x) + f(x)\frac{d}{dx}[g(x)]$$

Integrate it all wrt $x$:

$$\int \frac{d}{dx}[f(x)\,g(x)]\,dx = \int \frac{d}{dx}[f(x)]\,g(x)\,dx + \int f(x)\frac{d}{dx}[g(x)]\,dx$$

LHS: F.T.C. says $\int \frac{d}{dx}[\sim]\,dx = \sim$

$$f(x)\,g(x) = \int \frac{d}{dx}[f(x)]\,g(x)\,dx + \int f(x)\frac{d}{dx}[g(x)]\,dx$$

Rearrange:

$$\boxed{\int \frac{d}{dx}[f(x)]\,g(x)\,dx = f(x)g(x) - \int f(x)\frac{d}{dx}[g(x)]\,dx}$$

This is the integration by parts formula.

It says that we can "move the derivative from $f$ to $g$".

The idea is to "get rid of $g$" by taking its deriv.

Ex. $\int x \sin x\, dx = -x\cos x - \int -\cos x\,(1)\,dx$

$$\left.\begin{matrix} \frac{d}{dx}[f(x)] = \sin x & g(x) = x \\ f(x) = -\cos x & \frac{d}{dx}[g(x)] = 1 \end{matrix}\right\}$$

$= -x\cos x + \int \cos x\, dx$

$= \boxed{-x\cos x + \sin x + C}$

Ex. $\int \ln x \, dx = \int \ln x \cdot 1 \, dx = x \ln(x) - \int x \cdot \frac{1}{x} \, dx$

$\frac{d}{dx}[f(x)] = 1 \qquad g(x) = \ln(x)$

$f(x) = x \qquad \frac{d}{dx}[g(x)] = \frac{1}{x}$

$= x \ln x - \int 1 \, dx$

$= \boxed{x \ln x - x + c}$

Ex. $\int t^2 e^t \, dt$

$\frac{d}{dt}[f(t)] = e^t \qquad g(t) = t^2$

$f(t) = e^t \qquad \frac{d}{dt}[g(t)] = 2t$

$= t^2 e^t - \underbrace{\int 2te^t \, dt}$

$\frac{d}{dt}[f(t)] = e^t \qquad g(t) = 2t$

$f(t) = e^t \qquad \frac{d}{dt}[g(t)] = 2$

$= t^2 e^t - 2te^t + \int 2e^t \, dt$

$= \boxed{t^2 e^t - 2te^t + 2e^t + C}$

(*) Make a chart.

Ex. $\int e^x \sin x \, dx = e^x \sin x - \int e^x \cos x \, dx$

$= e^x \sin x - e^x \cos x - \int e^x \sin x \, dx$

$\Rightarrow 2 \int e^x \sin x \, dx = e^x \sin x - e^x \cos x$

$\Rightarrow \int e^x \sin x \, dx = \boxed{\frac{1}{2} e^x (\sin x - \cos x) + C}$

First:

let $u = g(x)$ $\qquad dv = \frac{d}{dx}(f(x))\,dx$

$du = \frac{d}{dx}[g(x)]\,dx \qquad v = f(x)$

$\Rightarrow \int u\,dv = uv - \int v\,du$

A few more Int. by Parts examples.

Ex. $\int \theta \sec^2\theta \, d\theta$

$u = \theta \qquad dv = \sec^2\theta \, d\theta$

$du = 1\,d\theta \qquad v = \tan\theta$

$$\Rightarrow \int \theta \sec^2\theta = \theta\tan\theta - \int \tan\theta \, d\theta$$

$$= \theta\tan\theta - \int \frac{\sin\theta}{\cos\theta}\,d\theta$$

$y = \cos\theta$

$dy = -\sin\theta\,d\theta$

$$= \theta\tan\theta + \int \frac{1}{y}\,dy$$

$$= \theta\tan\theta + \ln|y| + C$$

$$= \theta\tan\theta + \ln|\cos\theta| + C$$

$$= \boxed{\theta\tan\theta - \ln|\sec\theta| + C}$$

How to choose u:

L log

I inv. trig.

A alg. (polynom)

T trig

E exponential

Ex. A trick:

$\int x^4 e^x \, dx$

| | $u$ | $dv$ |
|---|---|---|
| + | $x^4$ | $e^x$ |
| − | $4x^3$ | $e^x$ |
| + | $12x^2$ | $e^x$ |
| − | $24x$ | $e^x$ |
| | $24$ | $e^x$ |
| − | $0$ | $e^x$ |

$$e^x\left[x^4 - 4x^3 + 12x^2 - 24x + 24\right] + C$$

Ex. $\int 5x^3 \sin(5x)\,dx$

| | $u$ | $dv$ |
|---|---|---|
| + | $5x^3$ | $\sin 5x$ |
| − | $15x^2$ | $-\frac{1}{5}\cos 5x$ |
| + | $30x$ | $-\frac{1}{25}\sin 5x$ |
| − | $30$ | $\frac{1}{125}\cos 5x$ |
| | $0$ | $\frac{1}{525}\sin 5x$ |

$+C$

# 6.2. Trig Integrals

Ex. $\int \cos^3 x \, dx = \int \cos^2 x \cos x \, dx$

$= \int (1-\sin^2 x) \cos x \, dx$

$u = \sin x \quad du = \cos x \, dx$

$= \int 1 - u^2 \, du$

$= u - \frac{1}{3} u^3 + c$

$= \boxed{\sin x - \frac{1}{3} \sin^3 x + c}$

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Ex. $\int \sin^5 x \cos^2 x \, dx = \int \sin^4 x \cos^2 x \sin x \, dx$

$= \int (1-\cos^2 x)^2 \cos^2 x \sin x \, dx$

$u = \cos x \quad du = -\sin x$

$= -\int (1-u^2)^2 u^2 \, du$

$= -\int u^2 (1 - 2u^2 + u^4) \, du$

$= -\int u^2 - 2u^4 + u^6 \, du$

$= -\frac{1}{3} u^3 + \frac{2}{5} u^5 - \frac{1}{7} u^7 + C$

$= \boxed{-\frac{1}{3} \cos^3 x + \frac{2}{5} \cos^5 x - \frac{1}{7} \cos^7 x + C}$

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Ex. $\int_0^{\pi} \sin^2 x \, dx \qquad \sin^2 x = \frac{1}{2}(1 - \cos 2x) \qquad \cos^2 x = \frac{1}{2}(1 + \cos 2x)$

$= \frac{1}{2} \int_0^{\pi} (1 - \cos 2x) \, dx$

$= \frac{1}{2} x - \frac{1}{4} \sin 2x \Big]_0^{\pi} = \frac{1}{2}\pi - 0 = \boxed{\frac{1}{2}\pi}$

Ex. $\int \sin^4 x \, dx$

Ex. $\int \tan^6 x \sec^4 x \, dx$ $\qquad \sec^2 x \, dx$

Ex. $\int \tan^5 \theta \sec^7 \theta \, d\theta$ $\qquad \tan\theta \sec\theta \, d\theta$

recall: $\boxed{\int \sec x \, dx = \ln|\sec x + \tan x| + C}$

trick: mult by $\dfrac{\sec x + \tan x}{\sec x + \tan x}$

Main idea: these suck, but we can do them.
leads to trig substitutions.

| | |
|---|---|
| $\sqrt{a^2 - x^2}$ | $1 - \sin^2\theta = \cos^2\theta$ |
| $\sqrt{a^2 + x^2}$ | $1 + \tan^2\theta = \sec^2\theta$ |
| $\sqrt{x^2 - a^2}$ | $\sec^2\theta - 1 = \tan^2\theta$ |
| let $x = a \begin{Bmatrix} \sin \\ \tan \\ \sec \end{Bmatrix} \theta$ | |

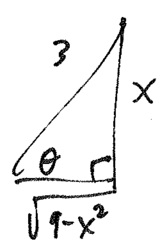
Ex. $\int \dfrac{\sqrt{9 - x^2}}{x^2} \, dx$

let $x = 3 \sin\theta \rightarrow \sin\theta = \dfrac{x}{3}$

$dx = 3 \cos\theta \, d\theta$

$\mapsto \int \dfrac{\sqrt{9 - 9\sin^2\theta}}{9\sin^2\theta} \, 3\cos\theta \, d\theta$

$= \int \dfrac{3 \cos\theta \cdot 3\cos\theta}{9 \sin^2\theta} \, d\theta$




$= \int \cot^2\theta \, d\theta = \int (\csc^2\theta - 1) \, d\theta = -\cot\theta - \theta + C$

$= \cancel{\ln|\sec\theta| + C} = \cancel{\ln\left|\dfrac{3}{\sqrt{9-x^2}}\right| + C} = \boxed{-\dfrac{\sqrt{9-x^2}}{x} - \arcsin\left(\dfrac{x}{3}\right) + C}$

arcsin$\left(\frac{x}{3}\right)$

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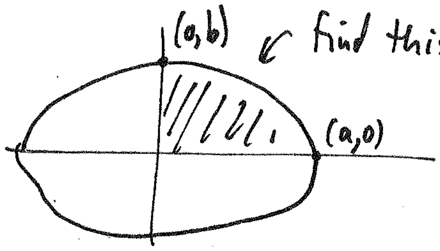
Ex. Find the area enclosed by the ellipse $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$.




find this & mult. by 4.

using +:

$$\frac{y^2}{b^2} = 1 - \frac{x^2}{a^2} = \frac{a^2 - x^2}{a^2}$$

$$y^2 = \frac{b^2}{a^2}(a^2 - x^2)$$

$$y = \pm \frac{b}{a}\sqrt{a^2 - x^2}$$

$$\frac{1}{4}A = \int_0^a \frac{b}{a}\sqrt{a^2-x^2}\,dx$$

let $x = a\sin\theta$

$dx = a\cos\theta\, d\theta$

$$= \frac{b}{a}\int_0^{\pi/2} \sqrt{a^2 - a^2\sin^2\theta}\; a\cos\theta\, d\theta$$

$$\begin{cases} \theta = \sin^{-1}\left(\frac{x}{a}\right) \\ \theta(0) = \sin^{-1}(0) = 0 \\ \theta(a) = \sin^{-1}(1) = \frac{\pi}{2} \end{cases}$$

$$= \frac{b}{a}\int_0^{\frac{\pi}{2}} a^2\cos^2\theta\, d\theta$$

$$= \frac{ba}{2}\int_0^{\frac{\pi}{2}} 1 + \cos 2\theta\, d\theta$$

$$= \frac{ba}{2}\left[\theta + \frac{1}{2}\sin 2\theta\right]_0^{\pi/2} = \frac{ba}{2}\cdot\frac{\pi}{2} - 0 = \frac{ab\pi}{4}$$

$$\Rightarrow A = \cancel{4}\cancel{\left(\frac{1}{4}\right)}ab\pi = \boxed{ab\pi}$$

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→ Ex. (60) $\int \frac{dt}{\sqrt{t^2 - 6t + 13}}$ evaluate by first completing the square.

First

$$= \int \frac{dt}{\sqrt{(t-3)^2 + 4}}$$

let $x = t-3$

$dx = dt$

$$= \int \frac{dx}{\sqrt{x^2+4}}$$

let $x = 2\tan\theta$

$dx = 2\sec^2\theta\, d\theta$

Solve for these w/ a $\Delta$.

$$= \int \frac{2\sec^2\theta}{2\sec\theta}\, d\theta = \int \sec\theta\, d\theta = \ln|\sec\theta + \tan\theta| + C$$

# 6.3. Partial Fractions

Ex. $\displaystyle\int \frac{x+5}{x^2+x-2}\,dx$

$$x^2+x-2 = (x+2)(x-1)$$

So, $\displaystyle\frac{x+5}{x^2+x-2} = \frac{A}{x+2} + \frac{B}{x-1}$

or $x+5 = A(x-1) + B(x+2)$

$x=1$: $6 = 3B$, $B=2$

$x=-2$: $3 = -3A$, $A=-1$

and $\displaystyle\frac{x+5}{x^2+x-2} = \frac{-1}{x+2} + \frac{2}{x-1}$

Then $\displaystyle\int \frac{x+5}{x^2+x-2}\,dx = \int \frac{-1}{x+2}\,dx + \int \frac{2}{x-1}\,dx = -\ln|x+2| + 2\ln|x-1| + C$

$$= \boxed{\ln\left|\frac{(x-1)^2}{x+2}\right| + C}$$

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Ex. $\displaystyle\int \frac{x^3+x}{x-1}\,dx$

$$\begin{array}{r|l} & x^2+2 \quad + \dfrac{2}{x-1} \\ x-1 & x^3+0x^2+x+0 \\ & x^3 \quad\quad -x \\ \hline & 2x \\ & 2x-2 \\ \hline & 2 \end{array}$$

$$= \int x^2+2+\frac{2}{x-1}\,dx$$

$$= \boxed{\tfrac{1}{3}x^3 + 2x + 2\ln|x-1| + C}$$

Ex. $\displaystyle\int \frac{x^2+2x-1}{2x^3+3x^2-2x}\,dx$

$$\begin{aligned}2x^3+3x^2-2x &= x(2x^2+3x-2)\\ &= x(2x^2+4x-x-2)\\ &= x[2x(x+2)-(x+2)]\\ &= x(2x-1)(x+2)\end{aligned}$$

$$\frac{x^2+2x-1}{2x^3+3x^2-2x} = \frac{A}{x} + \frac{B}{2x-1} + \frac{C}{x+2}$$

$$x^2+2x-1 = A(2x-1)(x+2) + B(x)(x+2) + C(x)(2x-1)$$

$x=0$: $\quad -1 = A(-1)(2) \qquad A = \frac{1}{2}$

$x=\frac{1}{2}$: $\quad \frac{1}{4}+1-1 = B(\frac{1}{2})(\frac{5}{2})$

$\qquad \frac{1}{4} = \frac{5B}{4} \qquad B = \frac{1}{5}$

$x=-2$: $\quad 4-4-1 = C(-2)(-5)$

$\qquad -1 = 10C \qquad C = \frac{-1}{10}$

$$\int \frac{x^2+2x-1}{2x^3+3x^2-2x}\,dx = \frac{1}{2}\int \frac{1}{x}\,dx + \frac{1}{5}\int \frac{1}{2x-1}\,dx - \frac{1}{10}\int \frac{1}{x+2}\,dx$$

$$= \boxed{\frac{1}{2}\ln|x| + \frac{1}{5}\ln|2x-1| - \frac{1}{10}\ln|x+2| + C}$$

Ex. $\displaystyle\int \frac{2x^2-x+4}{x^3+4x}\,dx$ * Irreducible quadratic factors.

$$x^3+4x = x(x^2+4)$$

$$\frac{2x^2-x+4}{x^3+4x} = \frac{A}{x} + \frac{Bx+C}{x^2+4}$$

$$2x^2-x+4 = A(x^2+4) + (Bx+c)x$$

$$2x^2-x+4 = Ax^2+4A + Bx^2 + Cx$$

$x^2$ : $2 = A+B$ $\quad B=1$

$x$ : $-1 = C$

#: $4 = 4A$ $\quad A=1$

so $\displaystyle\int \frac{2x^2-x+4}{x^3+4x}\,dx = \int \frac{1}{x}\,dx + \int \frac{x-1}{x^2+4}\,dx$ 9/5/12

$$= \int \frac{1}{x}\,dx + \frac{1}{2}\int \frac{2x}{x^2+4}\,dx - \int \frac{1}{x^2+4}\,dx$$

$$= \boxed{\ln|x| + \frac{1}{2}\ln|x^2+4| - \frac{1}{2}\arctan\left(\frac{x}{2}\right) + c}$$

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Ex. $\displaystyle\int \frac{x^4+1}{x(x^2+1)^2}\,dx$ * repeated factors

$$\frac{x^4+1}{x(x^2+1)^2} = \frac{A}{x} + \frac{Bx+C}{x^2+1} + \frac{Dx+E}{(x^2+1)^2}$$

$$x^4+1 = A(x^2+1)^2 + (Bx+c)x(x^2+1) + (Dx+E)x$$

$$= A(x^4+2x^2+1) + x(Bx^3+Cx^2+Bx+c) + Dx^2+Ex$$

$$= Ax^4+2Ax^2+A + Bx^4+Cx^3+Bx^2+Cx+Dx^2+Ex$$

$$= x^4(A+B) + x^3(c) + x^2(2A+B+D) + x(C+E) + (A)$$

$A+B=1$

$C=0$

$2A+B+D=0$

$C+E=0$

$A=1$

$A=1$

$C=E=B=0$

$D=-2$

$$\frac{1}{x}-\frac{2x}{(x^2+1)^2}$$

$$=\frac{x^4+2x^2+1-2x^2}{x(x^2+1)^2}=\frac{x^4+1}{x(x^2+1)^2}$$

So, $$\int\frac{x^4+1}{x(x^2+1)^2}\,dx=\int\frac{1}{x}\,dx+\int\frac{-2x}{(x^2+1)^2}\,dx=\boxed{\ln|x|+\frac{1}{x^2+1}+C}$$

$u=x^2+1$
$du=2x\,dx$

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6.4 : Project only. Using WolframAlpha, calculators, and charts (in back of book) to help integrate. For example:

17. $$\int\frac{du}{a^2+u^2}=\frac{1}{a}\arctan\left(\frac{u}{a}\right)+C$$

So, $$\int\frac{dx}{x^2+2x+10}=\int\frac{dx}{(x+1)^2+3^2}=\boxed{\frac{1}{3}\arctan\left(\frac{x+1}{3}\right)+C}$$

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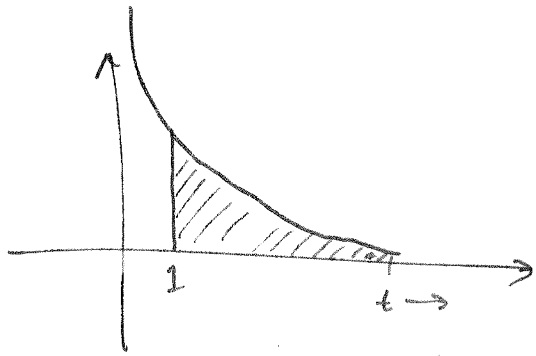
# 6.6 Improper Integrals

**Case I.** Integrals involving $\infty$.

**Ex.** $y = \frac{1}{x^2}$




For any $t > 1$ we can calculate $\int_1^t \frac{1}{x^2}\,dx = -\frac{1}{x}\Big]_1^t = \frac{1}{1} - \frac{1}{t}$

Reasonable conjecture: $\int_1^\infty \frac{1}{x^2}\,dx = \lim_{t\to\infty} \int_1^t \frac{1}{x^2}\,dx$

so $\int_1^\infty \frac{1}{x^2}\,dx = \lim_{t\to\infty}\left(1 - \frac{1}{t}\right) = 1 - 0 = \boxed{1}$

**Defn.** If $\int_a^t f(x)\,dx$ exist for all $t \geq a$, then

$$\int_a^\infty f(x)\,dx = \lim_{t\to\infty} \int_a^t f(x)\,dx$$ provided the limit exists.

If $\int_t^b f(x)dx$ exists for all $t \leq b$, then

$$\int_{-\infty}^b f(x)dx = \lim_{t\to-\infty} \int_t^b f(x)dx$$ iff it exists.

If these limits exist, then the integrals are said to be convergent, if not they are called divergent.

$\underline{\text{Ex}}$. $\int_1^\infty \frac{1}{x}\,dx$

$$= \lim_{t\to\infty} \int_1^t \frac{1}{x}\,dx = \lim_{t\to\infty}\left( \ln x \Big|_1^t \right) = \lim_{t\to\infty}\left(\ln t - \ln 1\right)$$

$$= \lim_{t\to\infty} \ln t - \lim_{t\to\infty} \ln 1$$

$$= \infty - 0 = \infty$$

so the integral <u>diverges</u>.

Thus $\int_1^\infty \frac{1}{x^2}\,dx$ converges $(=1)$, but $\int_1^\infty \frac{1}{x}\,dx$ diverges.

- Draw a picture.

$\boxed{\text{Exc}}$. $\int_1^\infty \frac{1}{x^n}\,dx$ Find out for what $n$ this integral will converge. (Exampl 4 in book)

$\underline{\text{Ex}}$. $$\int_{-\infty}^0 xe^x\,dx = \lim_{t\to-\infty} \int_t^0 xe^x\,dx = \lim_{t\to-\infty}\left(xe^x - e^x \Big|_t^0\right)$$

$$= \lim_{t\to-\infty}\left(0 - te^t - 1 + e^t\right)$$

$$= -\lim_{t\to-\infty} te^t - 1 + \underbrace{\lim_{t\to-\infty} e^t}_{0}$$

$$\lim_{t\to-\infty} te^t = \lim_{t\to-\infty} \frac{t}{e^{-t}} \overset{L'H}{=} \lim_{t\to-\infty} \frac{1}{-e^{-t}} = \frac{1}{-\infty} = 0$$

So, $\int_{-\infty}^0 xe^x\,dx = \boxed{-1}$ converges.

Ex. $\displaystyle\int_{-\infty}^{\infty} \frac{1}{1+x^2}\,dx$

what to do w/ this?

$\boxed{\text{Exc.}}\ \boxed{\text{RE \#51}}$ Show that If $f(x)$ is odd, then $\int_{-t}^{t} f(x)\,dx = 0$ for all $t$. There is no reason that every odd function should converge. e.g. $f(x) = x$.

Defn. If both $\int_a^{\infty} f(x)dx$ and $\int_{-\infty}^{a} f(x)dx$ are convergent, then we define

$$\int_{-\infty}^{\infty} f(x)\,dx = \int_{-\infty}^{a} f(x)\,dx + \int_{a}^{\infty} f(x)dx$$

i.e. $\int_{-\infty}^{\infty} f(x)dx$ converges iff it converges to both $\pm\infty$.

Ex. $$\int_{-\infty}^{\infty} \frac{1}{1+x^2}\,dx = \int_{-\infty}^{0} \frac{1}{1+x^2}\,dx + \int_{0}^{\infty} \frac{1}{1+x^2}\,dx$$

$$= \lim_{t\to-\infty} \int_t^0 \frac{1}{1+x^2}dx + \lim_{s\to\infty} \int_0^s \frac{1}{1+x^2}\,dx$$

$$= \lim_{t\to-\infty} \left(\arctan x \Big|_t^0\right) + \lim_{s\to\infty}\left(\arctan x \Big|_0^s\right)$$

$$= \arctan 0 - \lim_{t\to-\infty} \arctan t + \lim_{s\to\infty} \arctan s - \arctan 0$$

$$= 0 - \left(-\frac{\pi}{2}\right) + \left(\frac{\pi}{2}\right) - 0 = \frac{\pi}{2} + \frac{\pi}{2} = \boxed{\pi}$$ Converges.

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Project 2: §6.4

4.(a). $\int xe^x dx = e^x(x-1) + C$

Using Wolfram

$\int x^2 e^x dx = e^x(x^2-2x+2) + C$

$\int x^3 e^x dx = e^x(x^3-3x^2+6x-6) + C$

...

(c) Conjecture:

$$\int x^n e^x dx = e^x\left(x^n - \frac{d}{dx}(x^n) + \frac{d^2}{dx^2}(x^n) - + \cdots \frac{d^n}{dx^n}(x^n)\right) + C$$

where $\frac{d^n}{dx^n}(x^n) = n(n-1)(n-2)\cdots 1 = n!$

Math. induction:

1. initial case: $n=1$: $\int xe^x dx = e^x(x-1) + C = e^x\left(x - \frac{d}{dx}(x)\right) + C$ ✓
2. induction hypothesis: assume conjecture holds for some $n \geq 1$.
3. Prove for $n+1$:

$$\int x^{n+1} e^x dx = x^{n+1}e^x - \int \frac{d}{dx}\left[x^{n+1}\right] e^x dx \quad \leftarrow \text{by Int. by parts}$$

$$= x^{n+1}e^x - \int (n+1) x^n e^x dx$$

$$= x^{n+1}e^x - (n+1)\int x^n e^x dx \quad \leftarrow \text{by Conj.}$$

$$= x^{n+1}e^x - (n+1)e^x\left(x^n - \frac{d}{dx}(x^n) + \frac{d^2}{dx^2}(x^n) - + \cdots n!\right) + C$$

$$= x^{n+1}e^x - e^x\left[(n+1)x^n - (n+1)\frac{d}{dx}(x^n) + (n+1)\frac{d^2}{dx^2}(x^n) - + \cdots (n+1)n!\right] + C$$

$$= e^x\left[x^{n+1} - \frac{d}{dx}\left[x^{n+1}\right] + \frac{d^2}{dx^2}\left[x^{n+1}\right] - \frac{d^3}{dx^3}\left[x^{n+1}\right] + - \cdots (n+1)!\right] + C$$

$\square$

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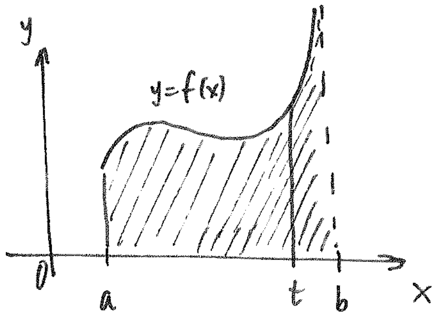
## Case II. Discontinuous Integrands




If $\int_a^t f(x)\,dx$ exists for all $t \in (a,b)$, then

$$\boxed{\int_a^b f(x)\,dx = \lim_{t\to b^-}\int_a^t f(x)\,dx}$$

also left limits (from the right)

Ex. $\displaystyle\int_2^5 \frac{1}{\sqrt{x-2}}\,dx = \lim_{t\to 2^+}\int_t^5 \frac{1}{\sqrt{x-2}}\,dx$ $\qquad u = x-2 \quad u(t) = t-2$
$\qquad du = dx \quad u(5) = 3$

$$= \lim_{t\to 2^+}\int_{t-2}^{3} u^{-1/2}\,du$$

let $s = t-2$
so $s \to 0^+$ as $t \to 2^+$

$$= \lim_{s\to 0^+}\left[2u^{1/2}\Big|_s^3\right]$$

$$= \lim_{s\to 0^+}\left[2\sqrt{3} - 2\sqrt{s}\right]$$

$$= 2\sqrt{3} - 0 = \boxed{2\sqrt{3}}$$

Ex. $\displaystyle\int_0^{\pi/2} \sec x\,dx$ $\qquad$ $\sec\frac{\pi}{2}$ is undefined.

$$= \lim_{t\to\frac{\pi}{2}^-}\int_0^t \sec x\,dx = \lim_{t\to\frac{\pi}{2}^-}\left[\ln|\sec x + \tan x|\Big|_0^t\right]$$

$$= \lim_{t\to\frac{\pi}{2}^-}\left[\ln|\sec t + \tan t| - \underbrace{\ln|\sec 0 + \tan 0|}_{=\ln 1 = 0}\right]$$

$$= \ln\left|\lim_{t\to\frac{\pi}{2}^-}\sec t + \lim_{t\to\frac{\pi}{2}^-}\tan t\right| = \infty \Rightarrow \text{diverges}$$

Ex. $\displaystyle\int_0^3 \frac{dx}{x-1} = \int_0^1 \frac{dx}{x-1} + \int_1^3 \frac{dx}{x-1}$

$$= \lim_{t\to 1^-}\left[\ln|x-1|\Big|_0^t\right] + \lim_{t\to 1^+}\left[\ln|x-1|\Big|_t^3\right]$$

$$= \underbrace{0 - \ln 0}_{+\infty} + \underbrace{\ln 2 - \ln 0}_{+\infty}$$

each piece diverges, so the whole diverges. //

9/10/12

**The Comparison Theorem.**

Suppose the f and g are continuous functions with

$f(x) \geq g(x) \geq 0$ for $x \geq a$

a) If $\int_a^\infty f(x)\,dx$ is convergent, then so is $\int_a^\infty g(x)\,dx$

b) If $\int_a^\infty g(x)\,dx$ is divergent, then so is $\int_a^\infty f(x)\,dx$.

Ex. $\displaystyle\int_0^\infty e^{-x^2}dx = \underbrace{\int_0^1 e^{-x^2}dx}_{\text{convergent}} + \int_1^\infty e^{-x^2}dx$

$e^{-x^2} \leq e^{-x}$ for all $x \geq 1$.

$$\int_1^\infty e^{-x}dx = \lim_{t\to\infty}\int_1^t e^{-x}dx = \lim_{t\to\infty} -e^{-x}\Big|_1^t = \lim_{t\to\infty} -\frac{1}{e^t} + \frac{1}{e}$$
$$= \boxed{\frac{1}{e}}$$

By comparison thm: $\int_1^\infty e^{-x^2}dx \leq \frac{1}{e}$ converges.

Using Complex analysis, one can show:

$$\int_0^\infty e^{-x^2}dx = \frac{\sqrt{\pi}}{2}$$

Ex. $\int_1^\infty \frac{1+e^{-x}}{x}\,dx$ diverges because $\int_1^\infty \frac{1}{x}\,dx$ diverges.

Ex. $\int_1^\infty \frac{dx}{x+e^{2x}}$. $\qquad x + e^{2x} > e^{2x}$ if $x \geq 1$

so $\frac{1}{x+e^{2x}} < \frac{1}{e^{2x}}$

and $\int_1^\infty \frac{dx}{x+e^{2x}} < \int_1^\infty \frac{1}{e^{2x}}\,dx$ which is convergent.

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Back to §6.5: Approximate integration