第一章　　多项式习题解答

P44.1　1) $f(x)=g(x)(\frac{1}{3}x-\frac{7}{9})+(-\frac{26}{9}x-\frac{2}{9})$

2) $f(x)=g(x)(x^2+x-1)+(-5x+7)$

P44.2　1) $x^2+mx-1\,|\,x^3+9x+q\Rightarrow$ 余式 $(p+1+m^2)x+(q-m)=0$

$\therefore\begin{cases}m=q\\ p=q^2-1\end{cases}$

方法二，

设 $x^3+px+q=(x^2+m-1)(x+q)\Rightarrow\begin{cases}m-q=0\\ -mq-1=p\end{cases}$ 同样。

2) $x^2+mx+1\,|\,x^4+px^2+q\Rightarrow$ 余式 $m(p+2-m^2)x-(q-p+1+m^2)=0$

$\therefore m(m^2+p-2)=0.\qquad m^2+p=1+q,(x^2=1-p+q)$

P44.3.1 用 $g(x)=x+3$ 除 $f(x)=2x^5-5x^3-8x$

解：

$\therefore\ f(x)=2(x+3)^5-30(x+3)^4+175(x+3)^3-495(x+3)^2+667(x+3)-327$

P44.3 .2)

$$\begin{aligned}&\therefore(x^3-x^2-\mathrm{x})\\&=(x-1+2i)^3+(2-8i)(x-1+2i)^2\\&-(12+8i)(x-1+2i)-(9-8i)\end{aligned}$$

即余式 $-9+8i$

商 $x^2-2ix-(5+2i)$

P44. 4.1).　$f(x)=x^5,x_0=1$：即

$\therefore\ f(x)=(x-1)^5+5(x-1)^4+10(x-1)^3+10(x-1)^2+5(x-1)+1$

当然也可以 $f(x)=x^5=[(x-1)+1]^5$

$=(x-1)^5+5(x-1)^4+\cdots+1$

P44.4　2) 结果

$$f(x)=x^4-2x^2+3=(x+2)^4-8(x+2)^3+22(x+2)^2-24(x+2)+11$$

3)

$$\begin{aligned}f(x)&=x^4+2ix^3-(1+i)x^2+3x+7+i\\&=(x+i-i)^4+2i(x+i-i)^3-(1+i)(x+i-i\ )^2-3(x+i-i)+7+i\\&=(x+i)^4-2i(x+i)^3+(1+i)(x+i)^2-5(x+i)+7+5i\end{aligned}$$

P45.5

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

$f(x)=(x+1)(x^3-3x-1)$

$\therefore(f(x),g(x))=x+1$

(2) $g(x)=x^3-3x^2+1$不可约

$f(x)=x^4-4x^3+1$不可约

$\therefore \left(f(x),g(x)\right)=1$

(3) $f(x)=x^4-10x^2+1=(x^2+2\sqrt{2}x-1)(x^2-2\sqrt{2}x-1)$

$g(x)=x^4-4\sqrt{2}x^3+6x^2+6\sqrt{2}x+1, f(x)=4\sqrt{2}(-x^3+2\sqrt{2}x^2+x)=(x^2-2\sqrt{2}x-1)^2$ $\therefore$

$\left(f(x),g(x)\right)=x^2-2\sqrt{2}x-1$

P45.6

(1) $f(x)=(x+1)^2(x^2-2)\qquad g(x)=(x^2-2)(x^2+x+1)$

$\because (x+1)^2\left[-(x+1)\right]+(x^2+x+1)(x+2)=1$

$\therefore (x^2-2)=-(x+1)f(x)+(x+2)g(x)$

(2) $f(x)=(x-1)(4x^3+2x^2-14x-y)$, $g(x)=(x-1)(2x^2+x-4)$

$=(x-1)f_1(x)\qquad =(x-1)g_1(x)$

而

$f_1(x)=g_1(x)\cdot 2x\text{-}3(2x+3)$

$g_1(x)=(2x+3)\cdot(x-1)$

$\therefore 1=(2x+3)(x-1)-g_1=(\frac{2x}{3}y_1-\frac{1}{3}f_1)(x-1)-g_1$

$\because x-1=-\frac{1}{3}(x-1)f(x)+(\frac{2}{3}x^2-\frac{2}{3}x-1)g(x)$

(3) $f(x)=x^4-x^3-4x^2+4x+1$, $g(x)=x^2-x-1$

$\therefore f(x)=g(x)(x^2-3)+(x-2)$, $g(x)=(x-2)(x+1)+1$

$\because 1=-(f-g(x^2-3))(x+1)+g$

$=-(x+1)f(x)+(x^3+x^2-3x-2)g(x)$.

P45.7

$f(x)=g(x)1+(1+t)x^2+(2-t)x+u=r(x)$

$g(x)=r(x)(\frac{1}{1+t}x+\frac{t-2}{(1+t)^2})+\frac{(t^2+t+u)+(t-2)^2}{(1+t)^2}x+(1-\frac{t-2}{(t+1)^2})u$

由题意$r(x)$与g(x)的公因式应为二次所以$r(x)\mid g(x)$

$$\therefore \begin{cases}\dfrac{t^3+3t^2-(u+3)t+(4-u)}{(1+t)^2}=0\\ \dfrac{t^2+t+3}{(1+t)^2}u=0\end{cases}$$

$t\neq -1$否则$r(x)$为一次的

$$\therefore \Rightarrow\begin{cases}t^3+3t^2-(u+3)t+(4-u)=0\\ (t^2+t+3)u=0\end{cases}$$

解出（ⅰ）当$u=0$时$t^3+3t^2-3t+4=0(t+4)(t^2-t+1)$

∴ $t=-4$或$t=\frac{1\pm\sqrt{3}\mathrm{i}}{2}=e^{\pm\frac{\pi}{3}\mathrm{i}}$

（ⅱ）当$u\neq 0$时，只有$t^2+t+3=0$，$\frac{1}{t+1}=-\frac{t}{3}$

$t^3+3t^2-(u+3)t+(4-u)\Rightarrow u=\frac{t^3+3t^2-3t+4}{t+1}=-\frac{t}{3}(t^3+3t^2-3t+4)$

∴ $u=-\frac{1}{3}[(t^2+t+3)(t^2+2t-8)+6t+24]=-2(t+4)$

即 $\begin{Bmatrix}u=-2(t+4)\\ t^2+t+3=0\end{Bmatrix}$

$t=\frac{-1\pm\sqrt{-11}}{2}$

P45、8 $d(x)\mid f(x),d(x)\mid g(x)$ 表明 $d(x)$ 是公因式

又已知：$d(x)$是$f(x)$与$g(x)$的组合　　表明任何公因式整除 $d(x)$

所以　$d(x)$　是一个最大的公因式。

P45，9. 证明 $(f(x)h(x),g(x)h(x))=(f(x),g(x)h(x))$　（$h(x)$ 的首系=1）

证：设 $(f(x)h(x),g(x)h(x))=m(x)$ 由

$(f(x),g(x))h(x)\mid f(x)h(x)$　　　$(f(x),g(x))h(x)\mid g(x)h(x).$

$\therefore (f(x),g(x))h(x)\mid m(x)$　　$\therefore (f(x),g(x))h(x)$ 是一个公因式。

设 $d(x)=(f(x),g(x))=u(x)f(x)+v(x)g(x).$

$\therefore d(x)h(x)=(f(x),g(x))h(x)=u(x)f(x)h(x)+v(x)g(x)h(x).$

而首项系数=1，又是公因式得（由 P45、8），它是最大公因式，且

$(f(x),g(x))h(x)=(f(x)h(x),g(x)h(x)).$

P45、10 已知 $f(x),g(x)$ 不全为 0。证明 $(\frac{f(x)}{(f(x),g(x))},\frac{g(x)}{(f(x),g(x))})=1.$

证：设 $d(x)=(f(x),g(x))$. 则 $d(x)\neq 0.$

设 $\frac{f(x)}{d(x)}=f_1(x)$,　　$\frac{g(x)}{d(x)}=g_1(x)$, 及 $d(x)=u(x)f(x)+v(x)g(x).$

所以 $d(x)=u(x)f_1(x)d(x)+v(x)g_1(x)d(x).$

消去 $d(x)\neq 0$ 得 $1=u(x)f_1(x)+v(x)g_1(x)$

P45.11　证：设 $(f(x),g(x))=d(x)\neq 0, f(x)=f_1(x)d(x), g(x)=g_1(x)d(x)$

∴ $u(x)f_1(x)d(x)+u(x)g_1(x)d(x)=d(x), u(x)f_1(x)+u(x)g_1(x)=1$

P45.12

设$uf+vg=1,\ u_1f+v_1h=1\ \Rightarrow uu_1f^2+ufv_1h+vgu_1f+vu_1gh=1$

$\therefore (uu_1f+uv_1h+vgu_1)f+(v_1u)gh=1\Rightarrow(f,gh)=1$.

P45.13

$\because\ (f_i,\mathrm{g}_i)=1$,

固定$i:(f_i,g_1g_2)=1$

$(f_i,g_1.g_2.g_n)=1$

P45.14

$(f,g)=1\Rightarrow uf+vg=1\Rightarrow(u-v)f+v(g+f)=1\Rightarrow(f,g+f)=1$

同理$(g,g+f)=1$.

由 12 题$(fg,f+g)=1$

令$g=g_1g_2\cdots g_n$

$\therefore$ 每个$i,(f_i,g)=1$

$\Rightarrow(f_1f_1,g)=1,$

$\Rightarrow\ (f_1f_2f_3,g)=1$,

$\Rightarrow\ (f_1f_2\cdots f_m,g_1g_2\cdots g_n)=1$（注反复归纳用 12 题）。

推广

若$(f(x),g(x))=1,$则$\forall$ m，n有$(f(x)^m,g(x)^n)=1$

P45,15

$f(x)=x^3+2x^2+2x+1,\ g(x)=x^4+x^3+2x^2+x+1$

解：$g(x)=f(x)(x-1)+2(x^2+x+1)$,

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

即(f(x)，g(x)) = x^2+x+1.

令$(x^2+x+1)=0$ 得 $\varepsilon_1=\dfrac{-1+\sqrt{3}i}{2},\varepsilon_2=\dfrac{-1-\sqrt{3}i}{2}$

$\therefore$ f(x)与g(x)的公共根为$\varepsilon_1,\varepsilon_2$.

P45.16 判断有无重因式

① $f(x)=x^5-5\ x^4+7x^3+2x^2+4x-8$　　② $f(x)=x^4+4x^2-4x-3$

解① $f'(x)=5x^4-20x^3+21x^2-4x+4$

$5f(x)=f'(x)(x-1)-3(2x^3-5x^2 4x+12)$

$_2\ f'(x)=(2x^3-5x^2-4x+12)(5x-\dfrac{15}{2})+\dfrac{49}{2}(x^2-4x+4)$

$(2x^3-5x^2-4x+12)=(x^2-4x+4)(2x+3)$

故 $f(x)$ 有重因式 $(x-2)^3$

② $f'(x)=4x^3+8x-4$

$f(x)=(x^3+2x-1)x+(2x^2-3x+3)$

$f'(x)=(2x^2-3x+3)(2x+3)+(11x-13)$

$11(2x^2-3x+3)=(11x-13)(2x-\frac{6}{11})+(33+\frac{6\times 13}{11})$

$\therefore (f(x).f'(x))=1$

P45.17 $t=?$时$f(x)=x^3-3x^2+tx-1$ 有重因式（有重根）

解. $f'(x)=3x^2-6x+t \quad 3f(x)=f'(x)(x-1)+(2t-6)x+(t-3)$

如 $t=3$ 则 有重因式：3 重因式 $(x-1)^3=f(x)$

如 $t\neq 3.$ 则 $2f'(x)=(2x+2)(3\times -\frac{15}{2})+(2t+\frac{15}{2})$

此时必须 $t=-\frac{15}{4}$ 有重因式 $f(x)=(x+\frac{1}{2})^2(x-4)$

P45.18 求多项式 $f(x)=x^3+px+q$ 有重根因式的条件

证 $f(x)=3x^2+p$

$3f(x)=(3x^2+p)x+2px+3q \qquad (p\neq 0)$

$(3x^2+p)=(2px+3q)(\frac{3}{2p}x-\frac{3a}{4p^2})+(p+\frac{27q^2}{4p^2})$

$\therefore 4p^3+27q^2=0$

p45.19 令 $f(x)=Ax^4+Bx^2+1,因为(x-1)^2\mid f(x),所以(x-1)\Big|\ \ f'(x))$

即 $f'(x)=4Ax^3+2Bx=(x-1)(ax^2+bx+c)$

$$\begin{cases} a=4A \\ b-a=0 \\ c-b=2B \\ -c=0 \end{cases} \qquad \begin{array}{l} \therefore 4A=a=b=-2B \\ \therefore 2A+B=0 \end{array}$$

又 $(x-1)f(x)\Rightarrow f(x)=(x-1)(a'x^3+b'x^2+c'x+d')$

$$\begin{cases} a'=A \\ b'-a'=0 \\ c'-b'=0 \\ -d'=1 \end{cases} \qquad \begin{array}{l} \therefore a'=A \\ b'=a' \\ -1-b'=B \end{array} \qquad \therefore A+B+1=0$$

$\therefore A=1,B=-2$

P46，20 证 $f(x)=1+x+\frac{x^2}{2!}+\cdots\frac{x^n}{n!}$ 无重因式（重根）

证：$f'(x)=f(x)-\frac{x^n}{n!}$

$\therefore (f',f)=(f,\frac{x^y}{n!})$ $\because (f,x)=1)$ $(f,x^n)=1 \Rightarrow f(x)$无重因式.

P46，21

g′(x)=$\frac{1}{2}$[f′(x)+ f′(a)]+$\frac{x-a}{2}f''(x)-f'(x)\Rightarrow$ g′(a)=0

又 g(a)=0

$$g''(x)=\frac{1}{2}f'''(x)+\frac{1}{2}f''(x)+\frac{x-a}{2}f'''(x)-f''(x)=\frac{1}{2}(x-a)f^{//}(x)\Rightarrow g''(a)=0$$

$$g^{///}(x)=\frac{1}{2}f'''(x)+\frac{x-a}{2}f^{(4)}x$$

$\therefore a$是$g(x),g^{/}(x),g^{//}(x),g^{///}(x)$根，且使$g^{//}(x)$的k+1重根

$\therefore$ a是g(x)的k+3重根.

P46，22

“$\Leftarrow$”必要性显然（见定理 6 推论 1）

“$\Rightarrow$”若x_0是f(x)的t重根，t＞k，

由定理$\Rightarrow f^{(k)}(x_0)=0$

若t＜k$\Rightarrow$ $f^{(k-1)}(x_0)\neq 0$，所以矛盾.

P46.23

例如 $f(x)=x^{m+1}$,则$x=0$是$f'(x)=(m+1)x^m$的m重根

但$x=0$不是$f(x)$的根.

P46.24 若$(x-1)\,f(x)^n$则$(x^n-1)\mid f(x^n)$

证若 $f(x)=(x-1)g(x)+r$(由上节课命题2)

$$f(x^n)=(x^n-1)g(x^n)+r=\overline{g}(x)+r\Rightarrow r=0$$

所以 $x^n-1\mid f(x^n)$

P46,25

证明 设x^2+x+1 的两个根$\varepsilon_1,\varepsilon_2,\varepsilon_i^3=1$

$$x^2+x+1=(x-\varepsilon_1)(x-\varepsilon_2)$$

$$\therefore\begin{cases} f_1(\varepsilon_1^3)+\varepsilon_1 f_2(\varepsilon_1^3)=0\\ f_2(\varepsilon_2^3)+\varepsilon_2 f_2(\varepsilon_2^3)=0\end{cases}$$

即$\begin{cases} f_1(1)+\varepsilon_1 f_2(1)=0 \\ f_1(1)+\varepsilon_2 f_2(1)=0 \end{cases}$

$\Rightarrow f_2(1)=0 \quad f_1(1)=0$

$\Rightarrow (x-1) \mid f_1(x), f_2(x)$.

P46、26 分解 x^n-1.

$$设\varepsilon_0=1 \quad \varepsilon_k=\cos\frac{2k\pi}{n}+i\sin\frac{2k\pi}{n}, k=0,1,2\cdots,n-1$$

$$(i)在\mathbb{C}中, x^n-1=\prod_{i=0}^{n-1}(x-\varepsilon_i)=(x-1)\prod_{k=1}^{n-1}(x-(\cos\frac{2k\pi}{n}+i\sin\frac{2k\pi}{n}))$$

$$(ii)在\mathbb{R}中, n为奇 \quad x^n-1=(x-1)\prod_{k=1}^{2m-2}(x-\varepsilon_k)=(x-1)\prod_{k=1}^{m-1}(x-\varepsilon_k)(x-\varepsilon_{n-k})$$

$$n=2m-1 \qquad =(x-1)\prod_{k=1}^{m-1}(x^2-2\cos\frac{2k\pi}{n}x+1)$$

$$当n=2m时: x^n-1=(x-1)(x+1)\prod_{k=1}^{m-1}(x^2-2\cos\frac{2k\pi}{n}x+1)$$

p46,27 求有理根：

（1）$x^3-6x^2+15x-14=f(x)$.

解：有理根可能为±1、±2、±7、±14。

∵当 a<0 时 f（a）<0，所以 f(x)的有理根是可能 1,2,7,14

f(1)=-4$\neq$0,f(2)=0,f(7)=140$\neq$0,f(14)=1764$\neq$0,只有一个x=2

（2）$4x^4-7x^2-5x-1=f(x)$.

解：有理根可能为±1、±$\frac{1}{2}$、±$\frac{1}{4}$，∵f(1)=-9≠0，f(-1)=1≠0,

f($\frac{1}{2}$)=-5,f(-$\frac{1}{2}$)=0,f($\frac{1}{4}$)=-2$\frac{43}{64}$,f(-$\frac{1}{4}$)=-$\frac{11}{64}$

所以f(x)只有一个有理根x=-$\frac{1}{2}$

（3）$f(x)=x^5+x^4-6x^3-14x^2-11x-3=f(x)$.

解：可能有有理根为±1、±3、f(1)=-32,f(-1)=0,f(3)=0　f(-3)=-96

故 f(x)有两个有理想-1,3

P46,28

①x^2+1：解 $y=y+1$, $x^2+1=y^2+2y+2$ 不可约

② $x^4-8x^3+12x^2+2$ 　解取P=2，由Eisenstein判别法，不可约。

③x^6+x^3+1,解令x=y+1 则

$x^6+x^3+1=y^6+6y^5+15y^4+21y^3+15y^2+9y+3$ 取P=3 即可。

④x^p+px+1 为奇素数

解：取y=x+1, $x^3+px+1=y^p+\sum_{i=1}^{p}(c_p^i y^{p-i}(-1)^i+p(y-1)+1$

$=y^p+\sum_{i=1}^{p-2}(c_p^i(-1)^i y^{p-i}+2py-p$

取 p 素数，即可

⑤$x^4+4kx+1$ 　　k为整数

解：令x=y+1,则$f(x)=x^4+4kx+1=y^4+4y^3+6y^2+(4+4k)y+(4k+2)$

取p=2，则 p2|4k+2 ,

即可由Eisenstein判别法，f(x)于 $\mathbb{Z}(\mathbb{Q})$ 上不可约。

P47.1:证$\because f_1,g_1$都是f,g的组合,所以若$c(x)$是f,g的公因式,则必有$c(x)\mid f_1,c(x)\mid g_1$,为$f_1,g_1$的公因式,即

$$CD\{f(x),g(x)\}\subseteq CD\{f_1(x),g_1(x)\}$$

反过来，得 $f(x)=\dfrac{1}{ad-bc}(df_1(x)-bg_1(x)),g(x)\dfrac{1}{ad-bc}(-cf_1(x)+ag_1(x))$

$\therefore f,g$也是f_1,g_1的组合,同上理,有

$$CD\{f_1(x),g_1(x)\}\subseteq CD\{f(x),g(x)\}$$

即，f与g和f_1与g_1的公因式一致,最大公因式也一致,那

$(f(x),\ g(x))=(f_1(x),g_1(x))$

注：不可约多项式也称既约定多项式

$f(x)\neq 0,a$,则$f(x)$不是既约,则称f(x)可约

P47,2

证：∵$d_1(x)f(x)\neq v_1(x)g(x)$⇒（f(x)，g(x)）=d(x).

$f(x)=f_i(x)d(x)$, $g(x)=g_i(x)d(x)$

∴$u_1(x)f_i(x)+v_1(x)g_1(x)=1$ 带余除法

令$u_1(x)=q_1(x)g_1(x)+u(x)$ 　　$\partial(u)<\partial(g_1(x))=\partial\left(\dfrac{g(x)}{g(x)+y(x)}\right)$

$v_1(x)=q_2(x)f_1(x)+v(x)$ $\partial(v)<\partial(f_1(x))=\partial(f(x)/(f(x),\ g(x))$

则$fu+gv+fg_1q_1+f_1gq_2$

$=f(x)u(x)+g(x)v(x)+f_1(x)g_1(x)d(x)(q_1+q_2)=d(x)$

∴$d-(uf+vg)=f_1g_1d(q_1+q_2)$,左边次数$<\partial(f_1)+\partial(y_1)+\partial(d)\leq$右边次数

故左、右两侧只有为 0，$d-(uf+vg)=0$

$u(x)f(x)+v(x)y(x)=d(x)$

且$\partial(u(x))<\partial(g_1(x)),\partial(v(x)<\partial(f_1(x))$

P47.3 若$f(x)$与$g(x)$互素,则$\forall m\geq 1, f(x^m$与$g(x^m)$也互素

证：$\because f(x)$与$g(x)$互素,$\because \exists u(x),v(x),u(x)f(x)+v(x)g(x)=1$

由推广令$\varphi(x)=x^m, u(x^m)f(x^m)+v(x^m)g(x^m)=1$

$\therefore (f(x^m),g(x^m))=1$,即$f(x^m)$与$g(x^m)$互素

P47 补 4

由定义有$(f_{1,}f_2\cdots f_s)=((f_1,\cdots,f_{s-1}),f_s)$,

证明$\exists d_i(x)$使得$u_1f_1+u_2f_2+\cdots+u_sf_s=(f_1,f_2\cdots f_s)$.

证：设$d=(f_1,f_2\cdots f_s)$，$d_1=(f_1\cdots f_{s-1})$ $d'=(d_1,f_s)$

显然$d\,|\,f_s$及$d|d_1\Rightarrow d|d'$，

反之，$d'\Rightarrow d|d_1'$，$d'\,|\,f_s\Rightarrow d|f_i$（$\forall i$）$\Rightarrow d'|d$。

又d,d'首项系数$=1\Rightarrow d=d'$.

证：由归纳方式$\exists u_i'$，使$u_1'f_1+\cdots+u_{s-1}'f_{s-1}=d_1$,又$\exists v,u$使得$vd_1+u_sf_s=d'$，

∴$d=d'=vd_1+u_sf_s=v\left(\sum_{i=1}^{s-1}u_i'f_i\right)+u_sf_s$ 令$u_i=vu_i'$ $i=1,2\cdots,s-1$

$=u_1f_1+\cdots+u_{s-1}f_{s-1}+u_sf_s$.

P48，补 5

证明 若：$f(x)g(x)$首项系数都$=1$ 则$[f,g]=\dfrac{fg}{(f,g)}$

证：令$(f,g)=d,f=f_1d,g=g_1d$,则$(f_1,g_1)=1$,设$m(x)=f_1g_1d$

显然① $f|m,\ g|m$, 故 m 是一个公倍式

再设② $f|l, g|l. \therefore d|l$，令l=dl_1，$\Rightarrow f_1|l_1, g_1|l_1$

$\because (f_1 g_1)=1$，$\therefore f_1 g_1|l_1 \Rightarrow f_1 g_1 d_1|l$　　即m|l

m 是 f、g 的一个最小 公倍　　式

即证得：$[f(x)、g(x)]=f_1(x)g_1(x)d(x)=\dfrac{f(x)\cdot g(x)}{(f(x)\cdot g(x))}$

$p48.7: f(x)$首项系数$=1.\partial(f(x))>0$,则 $f(x)$为某不可约多项式$p(x)$的方幂的充要条件是 $\forall g(x)$或者$(f,g)=1$或者$\exists m: f(x)|g^m(x)$

证明$"\Leftarrow"$反设不是则$f(x)=p_1^r(x)h(x)$,而$\partial(h(x))>0, p_1(x)+h(x)\Rightarrow$

$(p_1,h)=1$,即$h\nmid p_1$,取$g(x)=p_1(x)$,则$(f,g)\neq 1$,且$\forall\ \ m, f|g^m$,否则$h=p_1^s(x)$,矛盾.

"$\Rightarrow$" $f=p^r, \forall g(x)$,若$(p,g)=1\Rightarrow(p^r,g)=(f,g)=1$,若$(p,g)\neq 1\Rightarrow p|g\Rightarrow f|g^r(x)$

$p48.8: f(x)$首项系数$=1,\partial(f(x))>0$,则$f(x)$为某不可约多项式的方幂$\Leftrightarrow$

$\forall g(x)|h(x)$,由$f|gh\Rightarrow f|g$或者$\exists m, f(x)/h^m(x)$

证明$"\Rightarrow"$设$f=p^r$,若$f|gh,(p,h)=1\Rightarrow(p^r,h)=1\Rightarrow(f,h)=1\Rightarrow f|g$

$$(p,h)\neq 1\Rightarrow p\ |h\Rightarrow p^r|\ \ h^r\Rightarrow f|h^r(x)$$

$"\Leftarrow"$反设不是,则$f=p_1^r h$,而$\partial(h)>0, p_1+h$,令$g=p_1^r, h=h(x)$,则

$f|gh$却$f+g, f+h^m, \forall m(\because(p,h)=1\Rightarrow(p^r,h^m)=1)$

P48，补 9 证：$x^n+ax^{n-m}+b$没有重数＞2 的非零根

证：反设 $f(x)=x^n+ax^{n-m}+b$有k重根α,　(k＞2，$\alpha\neq 0$)

$g(x)=f'(x)=nx^{n-1}+a(n-m)x^{n-m-1}$有$k$重根$\alpha\neq 0$

$$\Rightarrow nx^{n-m-1}(x^m+\frac{a(n-m)}{n})\text{有重根}\alpha\neq 0$$

$\therefore h(x)=x^m+\dfrac{a(n-m)}{n}$　　有重根$\alpha\neq 0$

但$h'(x)=mx^{m-1}$　　　$\therefore (h(x)\ h'(x))=\begin{cases}1 \\ h'(x)\end{cases}$　　$\begin{cases}\text{无重数根} \\ \text{重根}0\end{cases}$

P48、补 10

$0\neq f(x)\in C[x]$,且$f(x)|\ \ f(x^n), n>1$,

证明$f(x)$的根只能为0或单位根(即满足某x^m=1的根).

证:设α为f(x)的根,由$f(x^n)==f(x)g(x)$

$\therefore f(\alpha^n)=0, \alpha^n$为$f(x)$的根,

$\therefore f(\alpha^{n^2})=0, \alpha^{n^2}$为$f(x)$的根,

$\Rightarrow \alpha, \alpha^n, \alpha^{n^2}, \alpha^{n^3}, \cdots$都为f(x)的根.

$\because f(x) \neq 0, \therefore f(x)$不可能有无限个根,其中必有相等者:

$\alpha^{n^i} = \alpha^{n^j} \quad$ (不妨设$i > j$),

$\therefore \alpha^{n^2}(\alpha^{n^i - n^j} - 1) = 0$,令$n^i - n^j = m$.

则或$\alpha = 0$,或α是$x^m = 1$的根.

P48、补 11 题:

$\because f'(x) \mid f(x) \Rightarrow f(x) = a(x-b)^n \quad \therefore f(x)$有n重根b.

补充P48 12题: $a_1, a_2 \cdots a_n$的两两不同. $F(x)=(x-a_1)(x-a_2)\cdots(x-a_n)$

证:(1)

$$\sum_{i=1}^{n} \frac{F(x)}{(f-a_1)F'(a_i)} = 1 \quad \because l_i = \frac{F(x)}{(x-a_i)F'(a_i)} = \frac{(x-a_1)(x-a_{i-1})(x-a_{i+1})\cdots(x-a_n)}{(a_i-a_1)(a_i-a_{i-1})(a_2-a_{i+1})(a_i-a_n)}$$

$l_i(a_j) = 0, l_i\ (a_i) = 1, \therefore \sum_{i=1}^{n} l_j(a_j) = 1, \forall j = 1\cdots n. \forall i, \sum_{i=1}^{n} l_i(x_i), i = 1\cdots n$

为$n-1$次多项式$, \therefore \sum_{i=1}^{n} l_i(x) = 1, (2)$设$f(x) = F(x)q(x) + r(x)$,则$f(a_i) = r(a_i)$,

而$n-1$形式多项式$\sum_{r=1}^{n} f(a_i)l_i(x) = h(x)\ : h(a_j) = f(a_j)$

$= r(a_j) \quad \therefore h(x) = r(x)$

p49、补 13 题:

(1)求 $f(x) \quad \partial(f(x)) < 4$且$f(2) = 3 \quad f(3) = -1 \quad f(4) = 0 \quad f(5) = 2$

$$l_1(x) = \frac{(x-3)(x-4)(x-5)}{(2-3)(2-4)(2-5)} = -\frac{1}{6}(x^3 - 12x^2 + 47x - 60)$$

$$l_2(x) = \frac{(x-2)(x-4)(x-5)}{(3-2)(3-4)(3-5)} = \frac{1}{2}x^3 - \frac{11}{2}x^2 + 19x - 20$$

$$l_3(x) = \frac{(x-2)(x-3)(x-5)}{(4-2)(4-3)(4-5)} = \frac{1}{2}x^3 + 5x^2 + \frac{31}{2}x + 15$$

$$l_4(x) = \frac{(x-2)(x-3)(x-4)}{(5-2)(5-3)(5-4)} = \frac{1}{6}x^3 + \frac{3}{2}x^2 + \frac{13}{3}x - 4$$

$$\therefore f(x) = \sum_{i=1}^{4} (l_i(x)) f(a_i) = 3l_1 - l_2 + 0 \cdot l_3 + 2l_4 = -\frac{2}{3}x^3 + \frac{17}{2}x^2 - \frac{203}{6}x + 42$$

②求一个二次多项式f(x), $f(0)=\sin 0, f(\frac{\pi}{2})=\sin\frac{\pi}{2}, f(\pi)=\sin\pi=0$.

$l_1(x)=\cdots,$

$l_2=\dfrac{(x-0)(x-\pi)}{(\frac{\pi}{2}-0)(\frac{\pi}{2}-\pi)},$

$l_3=\cdots,$

$\therefore f(x)=f(\frac{n}{2})l_2=\dfrac{x(x-\pi)}{-\frac{\pi^2}{4}}$

③ $f(x)$可能低次项:f(0)=1 $f(1)=2$ $f(2)=5$ $f(3)=10$

$l_1(x)=\dfrac{(x-1)(x-2)(x-3)}{(0-1)(0-2)(0-3)}=-\dfrac{1}{6}x^3+x^2-\dfrac{11}{6}x+1$

$l_2(x)=\dfrac{(x-0)(x-2)(x-3)}{(1-0)(1-2)(1-3)}=\dfrac{1}{2}x^3-\dfrac{5}{2}x+3x$

$l_3(x)=\dfrac{(x-0)(x-2)(x-3)}{(2-0)(2-1)(2-3)}=-\dfrac{x^3}{2}+2x^2+3x$

$l_4(x)=\dfrac{(x-0)(x-2)(x-3)}{(3-0)(3-1)(3-2)}=\dfrac{1}{6}x^3-\dfrac{1}{2}x^2+\dfrac{1}{3}x$

$\therefore f(x)=l_1(x)+2l_2(x)+5l_3(x)+10l_4(x)=x^2+1$

P49.补 14), $f(x)\in\mathbb{Z}[x], f(0), f(1)$奇, 则f(x)无整数根.

证:反设f(x)有整数数根m, 则x-m|f(x),

f(0)奇⇒-m奇 f(1)奇⇒1-m奇 矛盾!

第二章 行列式习题解答

P96.1 ① $\tau(134782695)=0+1+1+3+3+0+1+1=10\therefore 13478695$偶排列

② $\tau(217986354)=1+0+4+5+4+3+0+1=18\therefore 21798354$偶排列

③ $\tau(98765432)=8+7+6+\cdots 1+2+1=36\therefore 987654321$偶排列

P96.2①若 1274i56k9 偶则 i,k=3.8 或 8.3

τ (127435689)=5, τ (127485639)=10 ∴i=8, k=3

②若 1i25j4897 奇则 i,k=3，6 或 6.3

τ (132564897)=4　　　τ (162534897)=7　　　∴i=6　k=3

P96.3　3 1 2 4 3 5 →2 1 4 3 5 →2 5 4 3 1　→2 5 3 4 1 即得

P96.4　∵τ (n(n−1),⋯ 3 2 1)=$C_n^2=\dfrac{n(n-1)}{2}$

∴当 4|n或 4|n−1　即n=4k或n=4k+1 时，C_n^2为偶数，偶排列。

当n=4n+2,n=4n+3,则C_n^2为奇数，是奇排列

P96.5　排列π_1:$x_1x_2\cdots x_n$与π_2:$x_nx_{n-1}\cdots x_2x_1$中，任取两个数x_i,x_j

若x_i,x_j在π_1中有逆序,则在π_2中没有,反之在π_1中没有逆序,则π_2中有逆序,∴　$\tau(\pi_1)+\tau(\pi_2)=C_n^2$

即$\tau(x_nx_{n-1}\cdots x_2x_1)=C_n^2-\tau(x_1x_2\cdots x_n)$.

P97.6.由于$\tau(234516)+\tau(312645)=8.a_{23}a_{31}a_{42}+a_{56}a_{14}a_{65}$带正号

由$\tau(341562)+\tau(234165)=10\ \therefore a_{32}a_{43}a_{14}a_{51}a_{66}a_{23}$带正号

P96.7　$j_1j_2j_3j_4$由于$j_2=3$，∴$j_1j_3j_4$取　1、2、4 的排列

$j_1j_3j_4=124$

$\Rightarrow\tau(1324)=1,j_1j_3j_4\Rightarrow\tau(1342)=2;j_1j_3j_4=214\Rightarrow\tau(2314)=2$

$j_1j_3j_4=241\Rightarrow\tau(2341)=3.j_1j_3j_4=142\Rightarrow\tau(1342)=2;j_1j_3j_4=214\Rightarrow\tau(2314)=2$

$j_1j_3j_4=241\Rightarrow\tau(2341)=3,j_1j_3j_4=412\Rightarrow\tau(4312)=5;j_1j_3j_4=421\Rightarrow\tau(4321)=6$

$\therefore$取负号只有$-a_{11}a_{23}a_{32}a_{44},-a_{12}a_{23}a_{34}a_{41},-a_{14}a_{23}a_{31}a_{42}$

$P97.8(1)D=(-1)^{\tau(\mathrm{n}\cdots 321)}123\cdots(n-1)n=(-1)\dfrac{n(n-1)}{2}\bullet n$

$P97.8(2)D=(-1)^{\tau(23\cdots \mathrm{n}1)}123\cdots n=(-1)^{n-1}.n1$

$P97.8(3)D=(-1)^{\tau((\mathrm{n}-1)\ (\mathrm{n}-2)\cdots 21\mathrm{n})}123\cdots n=(-1)\dfrac{(n-1)(n-2)}{2}.n$

$$P97.9D=\sum_{j_1j_2j_3j_4j_5}(-1)^{(j_1j_2j_3j_4j_5)}aj_1bj_2cj_3dj_4ej_5$$

因后三行后三列为 0，所以非零的项只有，$j_3\le 2,j_4\le 2,j_5\le 2$,而$j_3,j_4,j_5$是互不相

同的数,这是不可能的,所以没有非 0 的项,D=0

P97.10　f(x)= $\begin{vmatrix} 2x & x & 1 & 2 \\ 1 & x & 1 & -1 \\ 3 & 2 & x & 1 \\ 1 & 1 & 1 & x \end{vmatrix}$ 求 x^4，x^3 的系数

解：∵行列式中每项由每行出一元相乘，故 x^4 必须将 2.3.4 行的x都取，这时第i行取第i列，这是行列式的一项，ax^4，系数为a=2。

x^3 项必有一元 a_{ij} 在对角线外，于是i行，j列的x不能再取了，故当i=1, j>2 时，至少去掉 3 个x, 不含 x^3 项了，对于i>2, j=2 同理

其它情形，至少去掉两个x且第一行（或第二列）的两个x只能取一个，故不含 x^3 项，只剩下i=1, j=2 时，a_{12} 本身是x项为

$(-1)^{(2134)}a_{12}a_{21}a_{33}a_{44}$=-x1xx=$-x^3$, 系数为-1

P97.11　$d=\sum_{j_1j_2\cdots j_n}(-1)^{\tau(j_1,j_2\cdots j_n)}\bullet 1=0$　故 $\sum$ 中 $+1$ 与 -1 一样多,即 $+$ 号, $-$ 号一样多,

也即奇偶排列一样多, $\therefore \mathrm{n}\ge 2$ 时, 奇偶排列各占一半.

P98.12①

$$p(x)=\begin{vmatrix} 1 & x & x^2 & \cdots & x^{n-1} \\ 1 & a_1 & a_1^2 & \cdots & a_1^{n-1} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 1 & a_{n-1} & a_{n-1}^2 & \cdots & a_{n-1}^{n-1} \end{vmatrix}=V\,x^{n-1}+\cdots(\text{按第一行展开})$$

$\because a_1a_2,\cdots a_{n-1}$ 两两不同 $\therefore V_{n-1}\neq 0$ 即 $\partial(p(x))=n-1$

$\because p(a_1)=p(a_2)=\cdots=p(a_{n-1})=0$ (总有两行相同)最多 $n-1$ 个根,

②即p(x)的所有根为 $a_1,a_2,\cdots,a_{n-1}$

$$P98.13\ ② \xrightarrow[\ ]{\substack{1\times(1)+3\\2\times(1)+3}} \begin{vmatrix} x & x & x+y \\ y & x+y & x \\ 2(x+y) & 2(x+y) & 2(x+y) \end{vmatrix} \xrightarrow{3(2(x+y))^{-1}} 2(x+y)$$

$$\begin{vmatrix} x & y & x+y \\ y & x+y & x \\ 1 & 1 & 1 \end{vmatrix} \xrightarrow{\substack{3(-x-y)+1\\3(-x)+2}} 2(x+y)\begin{vmatrix} -y & -x & 0 \\ y-x & y & 0 \\ 1 & 1 & 1 \end{vmatrix}$$

$$=2(x+y)[-y^2+xy-x^2]=-2(x^3+y^3)$$

$$P48.13③\begin{vmatrix}3&1&1&1\\1&3&1&1\\1&1&3&1\\1&1&1&3\end{vmatrix}\xrightleftharpoons{P2.23.3.4(例)}(3+(4-1)\cdot 1)(3-1)^{4-1}=6.2^3=48$$

P98.13④（法一）：

$$\begin{vmatrix}1&2&3&4\\2&3&4&1\\3&4&1&2\\4&1&2&3\end{vmatrix}=\begin{vmatrix}1&2&3&4\\0&-1&-2&-7\\0&-1&-8&-10\\0&-7&-10&-13\end{vmatrix}=-\begin{vmatrix}1&2&3&4\\0&1&2&7\\0&0&-4&4\\0&0&4&36\end{vmatrix}=\begin{vmatrix}1&2&3&4\\0&1&2&7\\0&0&4&-4\\0&0&0&40\end{vmatrix}=160$$

法二：

$$=\begin{vmatrix}10&2&3&4\\10&3&4&7\\10&4&1&2\\10&1&2&3\end{vmatrix}=10\begin{vmatrix}1&2&3&4\\0&1&1&-3\\0&2&-2&-2\\0&-1&-1&-1\end{vmatrix}=20\begin{vmatrix}1&2&3&4\\0&1&1&-3\\0&2&0&0\\0&-1&-1&-1\end{vmatrix}=20\begin{Vmatrix}1&2&3&4\\0&2&0&0\\0&0&1&-3\\0&0&-1&-1\end{Vmatrix}$$

$$=(-20)\begin{vmatrix}1&2&3&4\\0&2&0&0\\0&0&1&-3\\0&0&0&-4\end{vmatrix}=160$$

法三：

$f(x)=1+2x+3x^2+4x^3$ $\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4$为4次单位根$\pm 1,\pm i$

令$\varepsilon_1=1,\varepsilon_2=-1,\varepsilon_3=i,\varepsilon_4=-i$,则

行列式$d=(-1)^{c_{4-1}^2}f(1)f(-1)f(i)f(-i)$

$=(-1)^3\bullet 10\bullet(-2)\bullet(-2-2i)\bullet(-2+2i)=20[(-2)^2-(2i)^2]=160$

令

P98.13⑤解：

$$\begin{vmatrix}1+x&1&1&1\\1&1-x&1&1\\1&1&1+y&1\\1&1&1&1-y\end{vmatrix}=\begin{vmatrix}1&1&1&1&1\\0&1+x&1&1&1\\0&1&1-x&1&1\\0&1&1&1+y&1\\0&1&1&1&1-y\end{vmatrix}=\begin{vmatrix}1&1&1&1&1\\-1&x&0&0&0\\-1&0&-x&0&0\\-1&0&0&y&0\\-1&0&0&0&-y\end{vmatrix}=x^2y^2$$

$$\text{解法二, 设f(x, y)=}\begin{vmatrix}1+x & x & 1 & 1\\ 1 & 1 & x & 1\\ 1 & 1 & 1+y & 1\\ 1 & 1 & 1 & 1-y\end{vmatrix}\text{则第一行减第二行}\begin{vmatrix}x & x & 0 & 0\\ & & & \\ & & * & \\ & & & \end{vmatrix}$$

$$\therefore x\mid f(x,y)$$

$$\text{又因为}f(-x,y)=\begin{vmatrix}1-x & 1 & 1 & 1\\ 1 & 1+x & 1 & 1\\ 1 & 1 & 1+y & 1\\ 1 & 1 & 1 & 1-y\end{vmatrix}\xrightleftharpoons[]{\substack{\text{交换1,2行}\\ \text{再交换1,2列}}}\begin{vmatrix}1+x & 1 & 1 & 1\\ 1 & 1-x & 1 & 1\\ 1 & 1 & 1+y & 1\\ 1 & 1 & 1 & 1-y\end{vmatrix}=f(x,y).$$

$\therefore$ f(x, y)关于x是偶函数，即$x^2|f(x,y)$.

同理，$y|f(x,y)$，且也是偶函数，所以$y^2|f(x,y)$

$$\because \partial(f(x,y))\le 4 \qquad \therefore x^2y^2\mid f(x,y)\Rightarrow f(x,y)=kx^2y^2$$

而$f(x,y)$中x^2y^2的系数为1.　故有$f(x,y)=x^2y^2$.

P98　13⑥

$$\xrightleftharpoons[\substack{1\times(-1)+2\\ 1\times(-1)+3\\ 1x\times(-1)+4}]{}\begin{vmatrix}a^2 & 2a+1 & 4a+4 & 6a+9\\ b^2 & 2b+1 & 4b+4 & 6b+9\\ c^2 & 2c+1 & 4c+4 & 6c+9\\ d^2 & 2d+1 & 4d+4 & 6d+9\end{vmatrix}\xrightleftharpoons[\substack{2\times(-2)+3\\ 2\times(-3)+4}]{}\begin{vmatrix}a^2 & 2a+1 & 2 & 6\\ b^2 & 2b+1 & 2 & 6\\ c^2 & 2c+1 & 2 & 6\\ d^2 & 2d+1 & 2 & 6\end{vmatrix}\xrightleftharpoons[]{\text{性质5}}0$$

$$\xrightleftharpoons[2\times(-1)+3]{}\begin{vmatrix}246 & 427 & -100\\ 1014 & 543 & -100\\ -342 & 721 & -100\end{vmatrix}\xrightleftharpoons[\substack{3\times(246)+1\\ 3\times(427)+2}]{}\begin{vmatrix}0 & 0 & 1\\ 768 & 116 & 1\\ -588 & 294 & 1\end{vmatrix}\times(-100)\xrightleftharpoons[2\times(2)+1]{}$$

$$\begin{vmatrix}0 & 0 & 1\\ 1000 & 116 & 1\\ 0 & 294 & 1\end{vmatrix}\times(-100)\xrightleftharpoons[\text{性质7}]{}\begin{vmatrix}1 & 0 & 0\\ 1 & 116 & 1000\\ 1 & 294 & 0\end{vmatrix}\times(100)=-100\times\begin{vmatrix}1 & 0 & 0\\ 1 & 294 & 0\\ 1 & 116 & 1000\end{vmatrix}=-29400000$$

$$P98.14\quad \text{左}\xrightleftharpoons[\substack{2\times(1)+1\\ 3\times(1)+1\\ 1\times(\frac{1}{2})}]{}2\begin{vmatrix}a+b+c & c+a & a+b\\ a_1+b_1+c_1 & c_1+a_1 & a_1+b_1\\ a_2+b_2+c_2 & c_2+a_2 & a_2+b_2\end{vmatrix}\xrightleftharpoons[\substack{1\times(-1)+2\\ 1\times(-1)+3}]{}2\begin{vmatrix}a+b+c & -b & -c\\ a_1+b_1+c_1 & -b_1 & -c_1\\ a_2+b_2+c_2 & -b_2 & -c_2\end{vmatrix}$$

$$\xrightleftharpoons[\substack{2\times(1)+1\\ 2\times(1)+1}]{}2\begin{vmatrix}a & -b & -c\\ a_1 & -b_1 & -c_1\\ a_2 & -b_2 & -c_2\end{vmatrix}\xrightleftharpoons[\substack{2(-1)\\ 3(-1)}]{}\text{右}(-1)^2=\text{右}$$

P98.15 求出所有代数余子式

$$①\begin{vmatrix}1&2&1&4\\0&-1&2&1\\0&0&2&1\\0&0&0&3\end{vmatrix}\text{直接计算有}\begin{pmatrix}A_{11}&A_{12}&A_{13}&A_{14}\\A_{21}&A_{22}&A_{23}&A_{24}\\A_{31}&A_{32}&A_{33}&A_{34}\\A_{41}&A_{42}&A_{43}&A_{44}\end{pmatrix}=\begin{pmatrix}-6&0&0&0\\-12&6&0&0\\15&-6&-3&0\\7&0&1&-2\end{pmatrix}$$

$$②\begin{vmatrix}1&-1&2\\3&2&1\\0&1&4\end{vmatrix}\text{直接计算有}\begin{pmatrix}A_{11}&A_{12}&A_{13}\\A_{21}&A_{22}&A_{23}\\A_{31}&A_{32}&A_{33}\end{pmatrix}=\begin{pmatrix}7&-12&3\\6&4&-1\\-5&5&5\end{pmatrix}$$

P99.16①

$$=-\begin{vmatrix}-1&+3&+5&1&2\\2&0&1&2&1\\0&1&2&-1&4\\3&3&1&2&1\\2&1&0&3&5\end{vmatrix}\begin{matrix}1\times(2)+2\\1\times(3)=4\\\underline{\underline{1\times(2)+5}}\end{matrix}\begin{vmatrix}-1&3&5&1&2\\0&6&11&4&5\\0&1&2&-1&4\\0&12&16&5&7\\0&7&10&5&9\end{vmatrix}\begin{matrix}2(-)3\\\underline{\underline{2(-1)}}\end{matrix}\begin{vmatrix}-1&3&5&1&2\\0&-1&-2&1&4\\0&6&11&4&5\\0&12&16&5&7\\0&7&10&5&9\end{vmatrix}$$

$$\begin{matrix}2\times(6)+3\\2\times(2)+4\\\underline{\underline{2\times(7)+5}}\end{matrix}\begin{vmatrix}-1&3&5&1&2\\0&-1&-2&1&-4\\0&0&-1&-1&9\\0&0&-8&17&-41\\0&0&-4&12&-19\end{vmatrix}\begin{matrix}3(-1)\\3\times(8)+4\\\underline{\underline{3\times(4)+5}}\end{matrix}\begin{vmatrix}-1&3&5&1&2\\0&-1&-2&1&-4\\0&0&-1&-1&9\\0&0&-8&63&111\\0&0&0&-28&57\end{vmatrix}\underline{\underline{4\times(-2)+3}}$$

$$\begin{vmatrix}-1&3&5&1&2\\0&-1&-2&1&-4\\0&0&-1&-10&19\\0&0&0&-7&-3\\0&0&0&-28&57\end{vmatrix}$$

$$\begin{matrix}1\times(-1)\\2\times(-1)\\\underline{\underline{4\times(-4)+5}}\end{matrix}\begin{vmatrix}1&-&-5&-1&-2\\0&1&2&-1&4\\0&0&1&-10&19\\0&0&0&-10&-3\\0&0&0&0&69\end{vmatrix}=(-7)69=-483$$

P99.16②

$$\underline{\underline{\begin{matrix}1\times(2)\\5\times(2)\\4\times(2)\end{matrix}}}\ \frac{1}{8}\begin{vmatrix}2&1&0&4&-2\\2&0&-1&2&2\\3&2&1&1&0\\1&-1&0&2&2\\4&2&6&0&1\end{vmatrix}\ \underline{\underline{\begin{matrix}1\to4\\1\times(2)+2\\1\times(-3)+3\\1\times(2)+4\\1\times(-4)+5\end{matrix}}}\ \frac{1}{8}\begin{vmatrix}1&-1&0&2&2\\0&2&-1&-2&-2\\0&5&1&-5&-6\\0&3&0&0&-6\\0&6&6&-8&-7\end{vmatrix}$$

$$\underline{\underline{\begin{matrix}2-4\\4\times(-1)+2\end{matrix}}}+\frac{1}{8}\begin{vmatrix}1&-1&0&2&2\\0&2&1&2&-4\\0&5&1&-5&-6\\0&2&-1&-2&-2\\0&6&6&-8&-7\end{vmatrix}$$

$$\underline{\underline{\begin{matrix}2\times(-5)+3\\2\times(-2)+4\\2\times(-8)+5\end{matrix}}}\ \frac{1}{8}\begin{vmatrix}1&-1&0&2&2\\0&2&1&2&-4\\0&0&-4&-15&-14\\0&0&-3&-6&6\\0&0&0&-20&17\end{vmatrix}\ \underline{\underline{\begin{matrix}4-3\\2\times\frac{1}{3}\\3\times(-4)+4\end{matrix}}}\ -\frac{3}{8}\begin{vmatrix}1&-1&0&2&2\\0&1&1&2&4\\0&0&-1&-2&2\\0&0&0&-7&6\\0&0&0&0&-\frac{1}{7}\end{vmatrix}$$

$$=-\frac{3}{8}\cdot1\cdot1\cdot(-1)\cdot7\cdot(\frac{1}{7})=\frac{3}{8}$$

P99.17①若

$j_1j_2\cdots j_n$中$j_n=n$,则j_{n-1},取j_{n-1}取$n-1$, j_{n-2}取$n-2\cdots$, $j_2=2$, $j_1=1$或若$j_n=1$,则

$\Rightarrow j_1=2, j_2=3,\cdots j_{n-1}=n$.故只有两项. $\tau(123\cdots n)=0$， $\tau(2,3,\cdots n1)=n-1$

$\therefore d=\sum=x^n+(-1)^{n-1}y^n$

P99.17②

$n=1$则$d=a_1-b_1$

$$n=2,则d=(a_1-b_1)(a_2-b_2)-(a_1-b_2)(a_2-b_1)$$
$$=a_1b_1-a_2b_2+a_1b_1-b_2a_2$$
$$=(a_2-a_1)(b_2-b_1)$$

$$当n\geq3时\quad\begin{vmatrix}a_1-b_1&b_1-b_2&\vdots&a_1-b_1\\a_2-b_2&b_1-b_2&\vdots&b_1-b_n\\\vdots&\vdots&\vdots&b_1-b_n\\a_n-b_1&b_1-b_n&\vdots&b_1-b_n\end{vmatrix}=0第2列与第n列成比例$$

$$P99.17③ \xrightleftharpoons[\substack{2\times(1)+1\\3\times(1)+1\\n\times(1)+1}]{} \begin{vmatrix} \sum_{i=1}^{m} x_i - m & x_2 & \vdots & x_n \\ \vdots & x_2 - m & \vdots & \vdots \\ \vdots & \vdots & \vdots & x_n \\ \sum_{i=1}^{m} x_i - m & x_2 & \vdots & x_{n-m} \end{vmatrix} \xrightleftharpoons[\substack{1(\sum_{i=1}^{n}(x_{i-m})^{-1})\\1\times(-x_2)+2\\1\times(-x_3)+3\\1\times(-x_n)+n}]{} \begin{vmatrix} 1 & 0 & \vdots & 0 \\ 1 & -m & \vdots & \vdots \\ \vdots & \vdots & \vdots & 0 \\ 1 & 0 & \vdots & -m \end{vmatrix}$$

$$(\sum_{i=1}^{h} X_i - m) = (\sum_{i=1}^{h} X_i - m)(-m)^{n-1} = (-1)^n (m - \sum_{i=1}^{h} X_i) m^{n-1}.$$

$$P99.17\ ④ \xrightleftharpoons[]{\substack{2\times(-1)+3\\2\times(i-4)+4}} \begin{vmatrix} -1 & 0 & 0 & \cdots & 0 \\ 2 & 2 & 2 & \cdots & 2 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 2 & 0 \\ 0 & 0 & \cdots & \cdots & n-2 \end{vmatrix} \xrightleftharpoons[]{\substack{\text{性质}\\1\leftrightarrow 2}} \begin{vmatrix} 2 & 2 & & \cdots & 2 \\ -1 & 0 & & \cdots & 0 \\ 0 & 0 & 1 & 0 & 0 \\ & & & 2 & \\ & & & & n-2 \end{vmatrix}$$

$$\xrightleftharpoons[1\leftrightarrow 2]{1(\frac{1}{2})} 2 \begin{vmatrix} 1 & 1 & 1 & \cdots & 1 \\ 0 & -1 & 0 & \cdots & \\ & 0 & 1 & & 0 \\ & & 0 & & \\ & 0 & 0 & & n-2 \end{vmatrix}$$

=−2 • (n−2)!　　　(n⩾2)，且 n=1 时。D=1（左上角 1）

$P99.17.5$从最后一列开始，第n列加到第n−1列，再第n−1列加到第n−2列⋯，第2列加

$$= \begin{vmatrix} \frac{n(n+1)}{2} & \frac{n(n+1)}{2} & \frac{n(n-1)}{2}-3 & \cdots & 2n-1-n \\ 0 & -1 & 0 & \cdots & 0 \\ 0 & 0 & -2 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & 1-n \end{vmatrix}$$

$$= \frac{n(n+1)}{2} \bullet (-1)(-2)\cdots(1-n) = (-1)^{n-1} \bullet \frac{1}{2} \bullet (n+1)!$$

P100.18①:从第二列起：有列（第三列）

乘以 $-\frac{1}{a_{i-1}}$ 加到第一列，则有

$$D=\begin{vmatrix} a_o\sum_{i=2}^{n+1}\frac{1}{a_{i-1}} & 1 & 1 & \cdots & 1 \\ 0 & a_1 & 0 & \cdots & 0 \\ 0 & 0 & a_2 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & a_n \end{vmatrix}$$

$$=a_1a_2\cdots a_n(a_o-\sum_{i=2}^{n+1}\frac{1}{a_{i-1}})=a_1a_2\cdots a_n(a_o-\sum_{i=1}^{n}\frac{1}{a_i})$$

$$=a_oa_1\cdots a_n+\sum_{i=1}^{n}a_1\cdots a_{i-1}a_{i+1}\cdots a_n,\quad (\alpha_i\neq 0)$$

②

P100.18④

$$D_n=\begin{vmatrix} \cos a & 1 & & & \\ 1 & 2\cos a & 1 & & \\ & 1 & 2\cos a & \ddots & \\ & & \ddots & \ddots & 1 \\ & & & 1 & 2\cos a \end{vmatrix}=\cos n\alpha$$

证法一，用归纳法，D_1成立，

设$k<n$时$D_k=\cos k\alpha$,当$k=n$时,因为

$Dn=\cos 2\alpha D_{n-1}-1\cdot D_{n-2}=(2\cos\alpha\cdot\cos(n-1)\alpha-\cos(n-2)\alpha)=(\cos na+\cos(n-2a-\cos(n-2)a))$

$=\cos na$.证毕

证法二：

$\because D_n=2\cos cxD_{n-1}-D_{n-2}$ 找不出适当倍数左移.($i^2=-1$),

$D_n-(\cos\alpha+i\sin\alpha)D_{n-1}=(\cos\alpha-i\sin\alpha)[D_{n-1}-(\cos\alpha+i\sin\alpha)D_{n-2}]$

同理$D_n=(\cos a-i\sin a)D_{n-1}=(\cos(n-1)a+i\sin(n-1)a)(i\sin a)$

相减:$2i\sin a\mathrm{D_n}=i\sin a[\cos na+\sin na+\cos na-\sin na]$

即$D_n=\frac{1}{2}(2\cos na)=\cos na$.

P100.18⑤以第一行×(-1)加到后面各行

$$=\begin{vmatrix} 1+a_1 & 1 & 1 & \cdots & 1 \\ -a_1 & a_2 & 0 & \cdots & 0 \\ -a_1 & 0 & a_3 & 0 & 0 \\ -a_n & 0 & \cdots & 0 & a_n \end{vmatrix}$$

$$(\text{属于交行列式}) = a_1 \cdots a_n (1 + a_1 - \sum_{i=2}^{n} \frac{-a_1}{a_2})$$

$$= a_1 a_2 \cdots a_n (\frac{1}{a_1} + 1 + \sum_{i=2}^{n} \frac{1}{a_i})$$

要求 $(a_i \neq 0)$ $\quad = a_1 a_2 \cdots a_n (1 + \sum_{i=2}^{n} \frac{1}{a_i})$

p101.19①

$$D = \begin{vmatrix} 2 & -2 & 3 & 2 \\ 3 & -3 & 3 & 2 \\ 3 & -3 & -1 & 2 \\ 3 & -1 & 3 & -1 \end{vmatrix} = \begin{vmatrix} 2 & -1 & 3 & 2 \\ -3 & 0 & -6 & -4 \\ 1 & 0 & -4 & 0 \\ 1 & 0 & 0 & -3 \end{vmatrix} = \begin{vmatrix} -3 & -6 & -4 \\ 0 & -4 & 0 \\ 1 & 0 & -3 \end{vmatrix} = \begin{vmatrix} 0 & -6 & -13 \\ 0 & -4 & 3 \\ 1 & 0 & -3 \end{vmatrix} = -18 - 52 = -70$$

且 $D_1 = D_2 = D_3 = D_4 = -70 \quad \therefore \quad x_i = \frac{D_i}{D} = 1 \quad i = 1, 2, 3, 4$

P101，19②

$$D = \begin{vmatrix} 1 & 2 & 3 & -2 \\ 2 & -1 & -2 & -3 \\ 3 & 2 & -1 & 2 \\ 2 & -3 & 2 & 1 \end{vmatrix} = \begin{vmatrix} 1 & 2 & 3 & -2 \\ 0 & -5 & -8 & 1 \\ 0 & -4 & -10 & 8 \\ 0 & -7 & -4 & 5 \end{vmatrix} = \begin{vmatrix} 5 & 8 & 1 \\ 4 & 10 & 8 \\ 7 & 4 & 5 \end{vmatrix} = \begin{vmatrix} 0 & 0 & 1 \\ -36 & -54 & 8 \\ -18 & -36 & 5 \end{vmatrix} = \begin{vmatrix} 36 & 54 \\ 18 & 36 \end{vmatrix}$$

$$= 18^2 \begin{vmatrix} 2 & 3 \\ 3 & 2 \end{vmatrix} = 18^2 = 324$$

且 D_1=324，D_2=648，D_3=-324，D_4=-648，

$$\therefore x_1 = D_1 / D = 1, x_2 = D_2 / D = 2, x_3 = -1, x_4 = -2$$

P101 19 (3), 即 $D=\begin{vmatrix} 1 & 2 & -2 & 4 & -1 \\ 2 & -1 & 3 & -4 & 2 \\ 3 & 1 & -1 & 2 & -1 \\ 4 & 3 & 4 & 2 & 2 \\ 1 & -1 & -1 & 2 & -3 \end{vmatrix} = \begin{vmatrix} 0 & 3 & -1 & 2 & 2 \\ 0 & 1 & 5 & -8 & 8 \\ 0 & 4 & 2 & -4 & 8 \\ 0 & 7 & 8 & -6 & -14 \\ 1 & -1 & -1 & 2 & -3 \end{vmatrix} = \begin{vmatrix} 0 & -16 & 26 & -22 \\ 1 & 5 & -8 & 8 \\ 0 & -18 & 38 & -24 \\ 0 & -27 & 50 & -42 \end{vmatrix}$

$$=-\begin{vmatrix}2 & -2 & 2\\ -18 & 28 & -24\\ -9 & 22 & -18\end{vmatrix}=-\begin{vmatrix}0 & -2 & 0\\ 10 & 28 & 4\\ 13 & 22 & 4\end{vmatrix}=-(-2)\cdot(x-1)^{1+2}\begin{vmatrix}10 & 4\\ 13 & 4\end{vmatrix}=-8\begin{vmatrix}10 & 1\\ 13 & 1\end{vmatrix}=24$$

同理算出$d_1=96, d_2=-336, d_3=-96, d_4=169, d_5=312$

即得 $x_1=-4, x_2=-14, x_3=-4, x_4=7, x_5=13$

(消元法解)

$$\overline{A}=\begin{pmatrix}1 & 2 & -2 & 4 & -1 & -1\\ 2 & -1 & 3 & -4 & 2 & 8\\ 3 & 1 & -1 & 2 & -1 & 3\\ 4 & 3 & 4 & 2 & 2 & -2\\ 1 & -1 & -1 & 2 & -3 & -3\end{pmatrix}\xrightarrow[\text{再相减}]{\text{5行移最上}}\begin{pmatrix}1 & -1 & -1 & 2 & -3 & -3\\ 0 & 1 & -1 & 2 & 2 & 2\\ 0 & 1 & 5 & -8 & 8 & 14\\ 0 & 4 & 2 & -4 & 8 & 12\\ 1 & 7 & 8 & -6 & 14 & 10\end{pmatrix}\xrightarrow{\text{3行移到第2行再相减}}$$

$$\begin{pmatrix}1 & 0 & 4 & -6 & 5 & 11\\ 0 & 1 & 5 & -8 & 8 & 14\\ 0 & 0 & -16 & 26 & -22 & -40\\ 0 & 0 & -18 & 28 & -24 & -44\\ 0 & 0 & -27 & 50 & 42 & -88\end{pmatrix}\xrightarrow[(5)\times(4)\text{的2倍}]{(3)-(4)\text{后再乘}\frac{1}{2}}$$

$$\begin{pmatrix}1 & 0 & 4 & -6 & 5 & 11\\ 0 & 1 & 5 & -8 & 8 & 14\\ 0 & 0 & 1 & -1 & 1 & 2\\ 0 & 0 & -18 & 28 & -24 & -44\\ 0 & 0 & 9 & -6 & 6 & 0\end{pmatrix}\xrightarrow{(4)+(5)\text{的2倍后乘以}\frac{1}{4}\text{再用3行的相反倍加到各行}}$$

$$\begin{pmatrix}1 & 0 & 0 & -2 & 1 & 3\\ 0 & 1 & 0 & -3 & 3 & 4\\ 0 & 0 & 1 & -1 & 1 & 2\\ 0 & 0 & 0 & 4 & -3 & -11\end{pmatrix}\xrightarrow{(5)\times\frac{1}{3}\text{后再乘相应倍加到各行}}\begin{pmatrix}1 & 0 & 0 & 0 & -1 & -9\\ 0 & 1 & 0 & 0 & 0 & -14\\ 0 & 0 & 1 & 0 & 0 & -4\\ 0 & 0 & 0 & 0 & 1 & 13\\ 0 & 0 & 0 & 0 & -1 & -6\end{pmatrix}$$

$$\xrightarrow[(5)+(4)\text{后再交换}(4),(5)]{(1)+(4)}\begin{pmatrix}1 & 0 & 0 & 0 & 0 & 4\\ 0 & 1 & 0 & 0 & 0 & -14\\ 0 & 0 & 1 & 0 & 0 & -4\\ 0 & 0 & 0 & 1 & 0 & 7\\ 0 & 0 & 0 & 0 & 1 & 13\end{pmatrix}\text{即得.}$$

P101，19④

$$D=\begin{vmatrix}5&6&0&0&0\\1&5&6&0&0\\0&1&5&6&0\\0&0&1&5&6\\0&0&0&1&15\end{vmatrix}=\frac{2^6-3^6}{2-3}=3^6-2^6=665$$

见例2,

$$D_n=\begin{vmatrix}\alpha+\beta&\alpha\beta&\\1&\alpha+\beta&\ddots\\&\ddots&\ddots\end{vmatrix}=\frac{\alpha^{n-1}-\beta^{n-1}}{\alpha-\beta}$$

取$\alpha=2,\beta=3$

且, $D_1=1507\ \ D_2=-1145\ \ D_3=703\ \ D_4=-395\ \ D_5=212$

$\therefore x_1=\frac{1507}{665},x_2=\frac{-229}{133},x_3=\frac{37}{35},x_4=-\frac{79}{133},x_5=\frac{212}{665}$

P101.20 解：

代入各a于f(x) $\begin{cases}c_0a_1{}^{n-1}+c_1a_1{}^{n-2}+\cdots c_{n-1}=b_1\\c_0a_2{}^{n-1}+c_1a_2{}^{n-2}+\cdots c_{n-1}=b_2\\c_0a_n{}^{n-1}+c_1a_n{}^{n-2}+\cdots c_{n-1}=b_n\end{cases}$

系数行列式：

$$d=\begin{vmatrix}a_1{}^{n-1}&a_1{}^{n-2}\cdots a_1&1\\a_2{}^{n-1}&a_2{}^{n-2}\cdots a_2&1\\a_n{}^{n-1}&a_n{}^{n-2}\cdots a_n&1\end{vmatrix}=\begin{vmatrix}1&a_1&a_1{}^2\cdots a_1{}^{n-1}\\1&a_2&a_2{}^2\cdots a_n{}^{n-1}\\\cdots&\cdots&\cdots\\1&a_n&a_n^2\cdots a_n^{n-1}\end{vmatrix}=(-1)C_n^2V_n'$$

由于$a_1,a_2\cdots a_n$两两不同, 故$V_n'\neq0,d\neq0$由Cramer法则, 存在

唯一解$C_0,C_1,C_2\cdots c_{n-1}$, 即有$f(x)=\sum_{i=0}^{n-1}C_ix^{n-1-i}$(唯一地)使$f(a_i)=b_i$

例P101.21 解： $\begin{cases}a_0&=13.60\\a_0+10a_1+100a_2+1000a_3=13.57\\a_0+20a_1+400a_2+8000a_3=13.55\\a_0+30a_1+900a_2+7000a_3=13.52\end{cases}$

$$d=\begin{vmatrix}1&0&0&0\\1&10&10^2&10^3\\1&20&20^2&20^3\\1&30&30^2&30^3\end{vmatrix}\begin{matrix}=1.2\times10^7\\=(1a,20,30\cdot(20-10)(30-10)\cdot(30-20))\end{matrix}$$

$d_0=1.632\times10^8, d_1=-50000, d_2=1800, d_3=-40$

$a_0={do}/{d}=13.6, a_1=-\frac{25}{6}\times10^{-3}, a_2=1.5\times10^{-4}, a_3=-\frac{1}{3}\times10^{-5}$

用消元法: $\begin{pmatrix}1&0&0&0&13.6\\1&10&100&1000&13.57\\1&20&400&8000&13.55\\1&30&900&27000&13.52\end{pmatrix}\to\begin{pmatrix}1&0&0&0&13.6\\0&10^3&10^4&10^5&-3\\0&2\times10^3&4\times10^4&5\times50^5&-5\\0&3\times30^3&9\times10^4&27\times10^5&-8\end{pmatrix}$

$$\to\begin{pmatrix}1&0&0&0&13.6\\0&10^3&10^4&10^5&-3\\0&0&2\times10^4&6\times10^5&1\\0&0&6\times10^4&24\times10^5&1\end{pmatrix}\to\begin{pmatrix}1&0&0&0&13.6\\0&10^3&10^4&10^5&-3\\0&0&2\times10^4&6\times10^5&1\\0&0&0&6\times10^5&-2\end{pmatrix}\to(\text{略})$$

$h=13.6-\frac{25}{6}\times10^{-3}\times t+\frac{3}{2}\times10^{-4}\times t^2-\frac{1}{3}\times10.5\times t^3(t=°c, h={g}/{cm_3})$

故当t=15°c时, h=13.56(精确)-(${g}/{cm^3}$)

当t=40°c时, h=13.46(书上答案13.48是错的)

P102 补 1

$$D_1=\sum_{j_1j_2\cdots j_n}\begin{vmatrix}a_{1j_1}&a_{1j_2}&\cdots&a_{1j_n}\\a_{2j_1}&a_{2j_2}&\cdots&a_{2j_n}\\\cdots&\cdots&\cdots&\cdots\\a_{nj_1}&a_{nj_2}&\cdots&a_{nj_n}\end{vmatrix}\quad 设D=|a_{ij}|$$

$$\therefore D_1=\sum_{j_1j_2\cdots j_n}(-1)^{\tau(j_1j_2\cdots j_n)}D=\left(\sum_{j_1j_2\cdots j_n取遍}(-1)^{\tau(j_1j_2\ldots j_n)}\right)D=0$$

(n≥2 奇偶排列各半)

当 n=1 时,

$$P102 \quad 补2 \because D=\sum_{j_1 j_2\cdots j_n}(-1)^{\tau(j_1 j_2\cdots j_n)} a_{1j_1}(t)a_{2j_2}(t)\cdots a_{nj_n}(t))$$

$$\therefore \frac{d}{dt}D=\sum_{j_1 j_2\cdots j_n}(-1)^{\tau(j_1 j_2\cdots j_n)}(\sum_{k=1}^{n} a_{1j_1}(t)\cdots a_{k-1j_{k-1}}(t)\frac{da_{kjk}(t)}{dt}a_{k+1j_{k+1}}\cdots a_{nj_n}(t))$$

$$=\sum_{k=1}^{n}(\sum_{j_1,j_2\cdots j_n}(-1)\tau^{(j_1,j_2\cdots j_n)})a_{1j_1}(t)a_{2j_2}(t)\cdots a_{k-1j_{k-1}}(t)\frac{da_{kj_k}(t)}{dt}a_{k+1j_{k+1}}\cdots a_{nj_n}(t))$$

$$=\sum_{k=1}^{n}\begin{vmatrix} a_{11}(t) & a_{12}(t) & a_{1n}(t) \\ \frac{d}{dt}a_{k1}(t) & \frac{d}{dt}a_{k2}(t) & \frac{d}{dt}a_{kn}(t) \\ a_{n1}(t) & a_{n2}(t) & a_{nn}(t) \end{vmatrix}$$

同理也有 $\frac{d}{dt}$ D= $\frac{d}{dt}$ D^T= $\sum_{n=1}^{n}\begin{vmatrix} a_{11}(t) & a_{21}(t) & a_{n1}(t) \\ \frac{d}{dt}(a_{1k}(t)) & \frac{d}{dt}a_{2k}(t) & \frac{d}{dt}a_{nk}(t) \\ \cdots & \cdots & \cdots \end{vmatrix}$

$$(转置)=\sum_{k=1}^{n}\begin{vmatrix} a_{11} & \frac{d}{dt}a_{1k}(t) & a_{1n} \\ a_{21} & \frac{d}{dt}a_{2k}(t) & a_{2n} \\ a_{n1} & \frac{d}{dt}a_{nk}(t) & a_{nn} \end{vmatrix}$$

$$左=\begin{vmatrix} a_{11}+x & a_{12}+x & \cdots & a_{1n}+x \\ a_{21}+x & a_{22}+x & \cdots & a_{2n}+x \\ & & & \\ a_{n1}+x & a_{u2}+x & \cdots & a_{u3}+x \end{vmatrix}=\left\|\begin{matrix} 1 & 0 & 0 & \cdots & 0 \\ 1 & a_{11}+x & a_{12}+x & & a_{1n}+x \\ 1 & a_{21}+x & a_{22}+x & & a_{2n}+x \\ & & & & \\ 1 & au_1+x & a_{u2}+x & & a_{2u}+x \end{matrix}\right|$$

P102 补 3 ①

$$=\begin{vmatrix} 1 & -x & -x\cdots-x \\ 1 & a_{11} & a_{12}\cdots a_{12} \\ 1 & a_{21} & a_{22}\cdots a_{2n} \\ 1 & a_{n1} & a_{n2}\cdots a_{nn} \end{vmatrix}=\begin{vmatrix} a_{11}\cdots a_{1n} \\ a_{n1}\cdots a_{nn} \end{vmatrix}+(-x)\sum_{i=1}^{n}(-1)^{1+(j+1)}\begin{vmatrix} 1 & a_{11}\cdots a_{1j-1} & a_{1j+1}\cdots a_{1n} \\ \vdots & & \\ 1 & a_{n1}\cdots a_{nj-1} & a_{nj+1}\cdots a_{nn} \end{vmatrix}$$

$$=D+X\sum_{i=1}^{n}(-1)^{j+1}\left(\begin{vmatrix} a_{11}\cdots a_{1j-1} & a_{1j+1}\cdots a_{1n} \\ a_{21}\cdots a_{2j-1} & a_{2j+1}\cdots a_{2n} \\ a_{n1}\cdots a_{nj-1} & a_{nj+1}\cdots a_{nn} \end{vmatrix}\right)(-1)^{j-1}$$

$$=D+X\sum_{j=1}^{n}\left(\sum_{i=1}^{n}1\bullet Aij\right)=D+X\sum_{i=1}^{n}\sum_{j=1}^{n}Aij$$

补 3 ②在①中令 X=1

$$\sum_{i=1}^{n}\sum_{j=1}^{n}A_{ij}=\begin{vmatrix} a_{11}+1 & a_{12}+1 & \vdots a_{1n}+1 \\ a_{21}+1 & a_{22}+1 & \vdots a_{2n}+1 \\ \vdots & \vdots & \vdots\quad\vdots \\ a_{n1}+1 & a_{n2}+1 & a_{nn}+1 \end{vmatrix}-D=$$

$$\begin{vmatrix} a_{11}-a_{12} & a_{12}-a_{13} & \cdots & a_{1n-1}-a_{1n} & a_{1n}+1 \\ a_{21}-a_{22} & a_{22}-a_{23} & \cdots & a_{2n-1}-a_{2n} & a_{2n}+1 \\ \cdots & & \cdots & & \cdots \\ a_{n1}-a_{n2} & a_{n2}-a_{n3} & \cdots & a_{nn-1}-a_{nn} & a_{nn}+1 \end{vmatrix}-\begin{vmatrix} a_{11}-a_{12} & a_{12}-a_{13} & \cdots & a_{1n-1}-a_{1n} & a_{1n} \\ a_{21}-a_{22} & a_{22}-a_{23} & \cdots & a_{2n-1}-a_{2n} & a_{2n} \\ \cdots & & \cdots & & \cdots \\ a_{n1}-a_{n2} & a_{n2}-a_{n3} & \cdots & a_{nn-1}-a_{nn} & a_{nn} \end{vmatrix}$$

$$\begin{vmatrix} a_{11}-a_{12} & a_{12}-a_{13} & \cdots & a_{1n-1}-a_{1n} & 1 \\ a_{21}-a_{22} & a_{22}-a_{23} & \cdots & a_{2n-1}-a_{2n} & 1 \\ \cdots & & \cdots & & \cdots \\ a_{n1}-a_{n2} & a_{n2}-a_{n3} & \cdots & a_{nn-1}-a_{nn} & 1 \end{vmatrix}$$

P103 补 4②：以第一行×(- $\frac{\beta}{\alpha}$)加到后面各行

$$\begin{vmatrix} \lambda & \alpha & \alpha & \cdots & \alpha \\ b-\frac{\beta\lambda}{\alpha} & \alpha-\beta & 0 & 0 & 0 \\ b-\frac{\beta\lambda}{\alpha} & 0 & \alpha-\beta & 0 & 0 \\ b-\frac{\beta\lambda}{\alpha} & 0 & 0 & 0 & \alpha-\beta \end{vmatrix}$$

$$=(\alpha-\beta)^{n-1}(\lambda-\sum_{i=2}^{n}\frac{\alpha b-\beta\lambda}{\alpha-\beta})$$

$$=\lambda(\alpha-\beta)^{n-1}-(n-1)(\alpha b-\beta\lambda)(\alpha-\beta)^{n-2}$$

P103 补 4、③ 见上面 4④得

$$D^n=[a(x+a)^n+a(x-a)^n]/2a=\frac{1}{2}\left[(x+a)^n+(x-a)^n\right]$$

P103 补 4④

$$D_n=\begin{vmatrix} & & y\\ & & y\\ * & & \vdots\\ z\,z\cdots z & & x-y+y\end{vmatrix}=\begin{vmatrix} & & y\\ & & y\\ * & & \vdots\\ oo & \cdots o & x-y\end{vmatrix}+\begin{vmatrix}x & y\ \cdots\ \cdots & y\\ * & & \\ z\,z & \cdots\ \cdots\ x & y\\ z\,z\cdots & \cdots\cdots z & y\end{vmatrix}$$

$$=(x-y)D_{n-1}+\begin{vmatrix}x-z & y-x & o & \cdots\cdots & o\\ o & x-z & y-x & \cdots & o\\ \cdots & \cdots & & & \cdots\\ o\cdots & & & x-z & o\\ z\cdots & \cdots & & z & y\end{vmatrix}=(x-y)D_{n-1}+y(x-z)^{n-1}\qquad (i)$$

y与z的对称位置有$Dn=(x-z)D_{n-1}+z(x-y)^{n-1}$ $\qquad (ii)$

$(1)\times(x-z)-(ii)\times(x-y)$：得$(y-z)Dn=y(x-z)^n-z(x-y)^n$

$\therefore Dn=\left[y(x-z)^n-z(x-y)^n\right]/(y-z)$

由令, y=a, z=−a, 便得

P103，补 5，f(x)是一个 n+1 级行列式

$$f(x)=\begin{vmatrix}1 & 0 & 0 & 0 & \cdots 0 & x\\ 1 & 2 & 0 & 0 & \cdots 0 & x^3\\ 1 & 3 & 3 & 0 & \cdots 0 & x^3\\ \vdots & \vdots & \vdots & \vdots & \cdots\vdots & \vdots\\ 1 & n & c_n^2 & c_n^3 & \cdots c_n^{n-1} & x_n\\ 1 & n+1 & c_{n+1}^2 & c_{n+1}^3 & \cdots c_{n+1}^{n-1} & x^{n-1}\end{vmatrix}$$

计算 f（x+1），由于前 n 列完全一样，故以下只标出第 n+1 列

$$f(x+1)=\begin{vmatrix}* & x+1\\ * & (x+1)^2\\ * & (x+1)_3\\ \cdots & \cdots\\ * & (x+1)^n\\ * & (x+1)^{n+1}\end{vmatrix}=\begin{vmatrix}* & x+1\\ * & x^2+2x+1\\ * & x^3+3x^2+3x+1\\ \cdots & \cdots\ \cdots\\ * & x^n+C_n^{n-1}x^{n-1}+\cdots+C_n^1x+1\\ * & x^{n+1}+(n+1)x^n+\cdots+C_n^2x^2+(n+1)x\ \ +1)\end{vmatrix}$$

$$=\begin{vmatrix} & x \\ & x^2 \\ * & x^3 \\ & \vdots \\ & x^n \\ & x^{n+1} \end{vmatrix}+\begin{vmatrix} & 0 \\ & 0 \\ * & 0 \\ & \vdots \\ & 0 \\ & 0 \\ & (n+1)x^n \end{vmatrix}+\begin{vmatrix} & 0 \\ & 0 \\ & 0 \\ & \vdots \\ * & 0 \\ & c_n^2 x^{n-1} \\ & c_{n+1}^2 x^{n-2} \end{vmatrix}+\cdots+\begin{vmatrix} & 0 \\ & 2x \\ * & 3x \\ & \vdots \\ & (n-1)x \\ & nx \\ & (n+1)x \end{vmatrix}+\begin{vmatrix} & 1 \\ & 1 \\ & 1 \\ * & \vdots \\ & 1 \\ & 1 \\ & 1 \end{vmatrix}$$

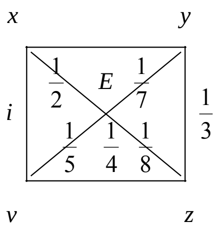
其余首项（可算出后面每个行列式的最后一列都与前面某列比例=0）

$$=f(x)+(\text{第2个行列式})D_2$$

$$\text{而}D_2=\begin{vmatrix} 1 & & & \\ & 2 & & \\ & & 3 & \\ * & & \ddots\, c_n^{n-1} & (n+1)xn \end{vmatrix}=(n+1)!x^n$$

$$\therefore f(x+1)-f(x)=(n+1)!x^n$$

P104 补 6 分别用 U、X、Y、Z 表子该些点的电位



$$\begin{cases} (x-y)\big/\frac{1}{2}+x\big/\frac{1}{6}+(x-0)\big/1=100 \\ (y-x)\big/\frac{1}{2}+x\big/\frac{1}{7}+(y-z)\big/\frac{1}{3}=100 \\ (x-y)\big/\frac{1}{2}+x\big/\frac{1}{3}+(x-0)\big/1=100 \\ (o-z)\big/\frac{1}{4}+u\big/\frac{1}{5}+(v-x)\big/1=100 \end{cases}\qquad \begin{cases} ax-2y \quad -\upsilon=100 \\ -2\times+12y-3z=100 \\ -3y+15z-4\upsilon=100 \\ -x\ -4z+10\upsilon=100 \end{cases}$$

$$D=\begin{vmatrix} a & -2 & 0 & -1 \\ -2 & 12 & -3 & 0 \\ 0 & -3 & 15 & 14 \\ -1 & 0 & -4 & 10 \end{vmatrix}=\begin{vmatrix} -1 & 0 & -4 & 10 \\ 0 & 12 & 5 & -20 \\ 0 & -3 & 15 & -4 \\ 0 & -2 & -36 & 89 \end{vmatrix}=\begin{vmatrix} 0 & 65 & -36 \\ -1 & +51 & -93 \\ 0 & -138 & 275 \end{vmatrix}=\begin{vmatrix} 65 & -36 \\ 138 & 275 \end{vmatrix}=\begin{vmatrix} 17875-4968 \end{vmatrix}$$

$$dx=210100,dy=188400,dz=183300,do=223400.\quad =12907$$

$$\therefore x=\frac{210100}{12907},y=\frac{188400}{12907},z=\frac{183300}{12907},\upsilon=\frac{223400}{12907}$$

第三章　　线性方程组习题参考答案

P154,T1

1)解:

$$\begin{pmatrix}1&3&5&-4&0&1\\1&3&2&-2&1&-1\\1&-2&1&-1&-1&3\\1&-4&1&1&-1&3\\1&2&1&-1&1&-1\end{pmatrix}\to\begin{pmatrix}1&3&5&-4&0&-1\\0&0&-3&2&1&-2\\0&-5&-4&3&-1&2\\0&-7&-4&5&-1&2\\0&-1&-4&3&1&-2\end{pmatrix}\to\begin{pmatrix}1&3&5&-4&0&1\\0&-1&-4&3&1&-2\\0&0&-3&2&1&-2\\0&0&16&-12&-6&12\\0&0&24&-16&-8&16\end{pmatrix}$$

$$\to\begin{pmatrix}1&3&5&-4&0&1\\0&-1&-4&3&1&-2\\0&0&1&-2&-1&2\\0&0&0&-4&-2&4\\0&0&0&0&0&0\end{pmatrix}\to\begin{pmatrix}1&3&5&0&0&1\\0&1&4&3&1&-2\\0&0&1&-2&-1&2\\0&0&0&-4&-2&4\\0&0&0&0&0&0\end{pmatrix}\to\begin{pmatrix}1&0&0&0&\frac{1}{2}&0\\0&1&0&0&\frac{1}{2}&-1\\0&0&1&0&0&0\\0&0&0&1&\frac{1}{2}&1\\0&0&0&0&0&0\end{pmatrix}$$

∴方程组的解是 $\begin{cases}x_1=-\frac{1}{2}k\\x_2=-1-\frac{1}{2}k\\x_3=0\\x_4=1-\frac{1}{2}k\\x_5=k\end{cases}$ k为任意数

2）解：

$$\begin{pmatrix}1&2&0&-3&2&1\\1&-1&-3&1&-3&2\\2&-3&4&-5&2&7\\9&-9&6&-16&2&25\end{pmatrix}\to\begin{pmatrix}1&-1&-3&1&-3&2\\0&3&3&-4&5&-1\\0&-1&10&-7&8&3\\0&0&33&-25&29&7\end{pmatrix}\to\begin{pmatrix}1&-1&-3&1&-3&2\\0&-1&10&-7&8&3\\0&0&22&-25&29&8\\0&0&33&-25&29&7\end{pmatrix}$$

$$\to\begin{pmatrix}1&-1&-3&1&-3&2\\0&1&-10&7&-8&-3\\0&0&33&-25&29&8\\0&0&0&0&0&-1\end{pmatrix}$$ 出现了（0,0,0,0,0,-1），无解

3）解：$\begin{pmatrix}1&-2&3&-4&4\\0&1&-1&1&-3\\&3&0&1&1\\0&-7&3&1&-3\end{pmatrix}\to\begin{pmatrix}1&-2&3&-4&4\\0&1&-1&1&-3\\0&5&-3&5&-3\\0&-7&3&1&-3\end{pmatrix}\to\begin{pmatrix}1&0&1&-2&-2\\0&1&-1&1&-3\\0&0&2&0&12\\0&0&-4&8&-24\end{pmatrix}$

$$\rightarrow\begin{pmatrix}1&0&0&-2&-8\\0&1&0&1&3\\0&0&1&0&6\\0&0&0&8&0\end{pmatrix}\rightarrow\begin{pmatrix}1&0&0&0&-8\\0&1&0&0&3\\0&0&1&0&6\\0&0&0&1&0\end{pmatrix}$$
有唯一解: x_1=-8, x_2=3, x_3=6, x_4=0

4）解：
$$\begin{pmatrix}3&4&-5&7&0\\2&-3&3&-2&0\\4&11&-13&16&0\\7&-2&1&3&0\end{pmatrix}\rightarrow\begin{pmatrix}1&7&-8&9\\2&-3&3&-2\\0&17&-19&20\\-1&-24&27&-29\end{pmatrix}\rightarrow\begin{pmatrix}1&7&-8&9\\0&-17&19&-20\\0&17&-19&20\\0&-17&19&-20\end{pmatrix}$$

$$\rightarrow\begin{pmatrix}1&7&-8&9\\0&-1&19/17&-20/17\\0&0&0&0\\0&0&0&0\end{pmatrix}\rightarrow\begin{pmatrix}1&7&-3/17&13/17\\0&-1&19/17&-20/17\\0&0&0&0\\0&0&0&0\end{pmatrix}$$

得解：
$$\begin{cases}x_1=\dfrac{3}{17}k-\dfrac{13}{17}l\\x_2=\dfrac{19}{17}k-\dfrac{20}{17}l\\x_3=k\\x_4=l\end{cases}$$

5）解：

$$\begin{pmatrix}2&1&-1&1&1\\3&-2&2&-3&2\\5&1&-1&2&-1\\2&-1&1&-3&4\end{pmatrix}\rightarrow\begin{pmatrix}2&1&-1&1&1\\1&-3&3&-4&1\\1&-1&1&0&-3\\0&-2&2&4&3\end{pmatrix}\rightarrow\begin{pmatrix}1&1&1&0&-3\\0&-3&-3&1&7\\0&-1&2&-4&4\\0&-2&2&-4&3\end{pmatrix}\rightarrow\begin{pmatrix}1&-1&1&0&-3\\0&-3&-3&1&7\\0&-2&2&-4&4\\0&0&0&0&-1\end{pmatrix}$$
出现了（0,0,0,0,-1），无解

6）解：

$$\begin{pmatrix}1&2&3&-1&1\\3&2&1&-1&1\\2&3&1&-1&1\\2&2&2&-1&1\\5&5&2&0&2\end{pmatrix}\rightarrow\begin{pmatrix}1&2&3&-1&1\\0&-4&-8&3&-2\\0&-1&-5&2&-1\\0&-2&-4&4&-1\\0&0&0&0&0\end{pmatrix}\rightarrow\begin{pmatrix}1&0&-1&0&0\\0&1&5&-3&1\\0&0&12&-10&2\\0&0&0&0&0\\0&0&0&0&0\end{pmatrix}\rightarrow\begin{pmatrix}1&0&0&-\frac{5}{6}&\frac{1}{6}\\0&1&0&\frac{7}{6}&\frac{1}{6}\\0&0&1&-\frac{5}{6}&\frac{1}{6}\\0&0&0&0&0\\0&0&0&0&0\end{pmatrix}$$

一般解为
$$\begin{cases} x_1=\frac{1}{6}+\frac{5}{6}k \\ x_2=\frac{1}{6}-\frac{7}{6}k \\ x_3=\frac{1}{6}+\frac{5}{6}k \\ x_4=k\cdots \end{cases} \quad 或 \quad \begin{cases} x_1=(1+5x_4)/6 \\ x_2=(1-7x)/6 \\ x_3=(1+5x_4)/6 \\ x_4任意 \end{cases}$$

P154，T2

1）解：设$\beta=x_1\alpha_1+x_2\alpha_2+x_3\alpha_3+x_4\alpha_4$，则

$$\begin{cases} x_1+x_2+x_3+x_4=1 \\ x_1+x_2-x_3-x_4=2 \\ x_1-x_2+x_3-x_4=1 \\ x_1-x_2-x_3+x_4=1 \end{cases} \Rightarrow \begin{cases} x_1=5/4 \\ x_2=1/4 \\ x_3=-1/4 \\ x_4=-1/4 \end{cases}$$

$$\therefore \alpha=\frac{5}{4}\alpha_1+\frac{1}{4}\alpha_2-\frac{1}{4}\alpha_3-\frac{1}{4}\alpha_4$$

2）解：设$\beta=x_1\alpha_1+x_2\alpha_2+x_3\alpha_3+x_4\alpha_4$，则

$$\begin{cases} x_1+2x_2+x_3 \quad =0 \\ x_1+x_2+x_3+x_4=0 \\ 0+3x_2 \quad -x_4=0 \\ x_1+x_2 \quad -x_4=0 \end{cases} \Rightarrow \begin{cases} x_1=1 \\ x_2=0 \\ x_3=-1 \\ x_4=0 \end{cases}$$

即$\beta=\alpha_1-\alpha_3$

P155.T3

证明：设$k_1, k_2, \cdots, k_r$， l不全为 0，使$k_1\alpha_1+k_2\alpha_2+\cdots k_r\alpha_r+l\beta=0$

若$\ell=0$，则$k_1, \cdots, k_r$也不全为 0，而$k_1\alpha_1+\cdots k_r\alpha_r=0$矛盾.

$\therefore \ell\neq 0$，即$\beta=(-\frac{k_1}{l})\alpha_1+(-\frac{k_2}{l})\alpha_2+\cdots(-\frac{k_s}{l})\alpha_r$线性表出

P155.T4

证明：设$x_1+\alpha_1+x_2\alpha_2+\cdots+x_n\alpha_n=0$，则

$$\begin{cases} a_{11}x_1+a_{21}x_2+\cdots+a_{n1}x_n=0 \\ a_{12}x_1+a_{22}x_2+\cdots+a_{n2}x_n=0 \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ a_{1n}x_1+a_{2n}x_2+\cdots+a_{nn}x_n=0 \end{cases}$$

因为系数行列式$\left|(a_{ij})'\right|=\left|a_{ij}\right|\neq 0$，故上面方程组只有零解，于是$\alpha_1,\alpha_2,\cdots\alpha_n$线性无关。

P155.T5

证明：添加$t_{r+1},\cdots,t_n$，使$t_1, t_2,\cdots,t_r, t_{r+1},\cdots,t_n$两两不同

得向量组

$$\begin{aligned} &\alpha_1=(1,t_1,t_1^2,\cdots t_1^{n-1}) \\ &\alpha_r=(1,t_r,t_r^2,\cdots t_r^{n-1}) \\ &\alpha_{r+1}=(1,t_{r+1},t_{r+1}^2,\cdots t_{r+1}^{n-1}) \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ &\alpha_n=(1,t_n,t_n^2,\cdots t_n^{n-1}) \end{aligned}$$

由于$\alpha_1,\alpha_2,\cdots,\alpha_n$的分量作成一个Vandermonder行列式（公比两两不同）且不等于 0，由 上一题，$\alpha_1,\alpha_2,\cdots,\alpha_r,\cdots,\alpha_n$线性无关，于是它的任一部分线性无关

P155.T6

证：设$\beta_1=\alpha_2+\alpha_3$，$\beta_2=\alpha_3+\alpha_1$，$\beta_3=\alpha_1+\alpha_2$，

若$x_1\beta_1+s_2\beta_2+x_3\beta_3=0$，则即

$(x_2+x_3)\alpha_1+(x_3+x_1)\alpha_2+(x_1+x_2)\alpha_3=0$

即$\alpha_1, \alpha_2, \alpha_3$线性无关

$$\therefore \begin{cases} x_2+x_3=0 \\ x_1+x_3=0 \\ x_1+x_2=0 \end{cases}$$

$\therefore x_1, x_2, x_3$全为 0，即$\beta_1, \beta_2, \beta_3$线性无关。

而若$\alpha_1,\alpha_2,\alpha_3,\alpha_4$线性无关，则$\alpha_1+\alpha_2, \alpha_2+\alpha_3, \alpha_3+\alpha_4, \alpha_4+\alpha_1$,线性相关。

P155.T7

证明：设$\alpha_1,\alpha_2,\cdots,\alpha_s$(I)的一个极大无关组$\alpha_{i1}, \alpha_{i2},\cdots,\alpha_{ir}$(I)′ 及任一线性无关向量组$\alpha_{j1}, \alpha_{j2},\cdots,\alpha_{jr}$(I)″

任取（I）中的一个向量β有$\alpha_{j1},\cdots,\alpha_{jr}$, $\beta\leftarrow$(I)$\rightleftarrows$(I)′ 而(I)′ 中只有r个向量，由定理 2，α_{j1},α_{jr}，β线性相关，而本来(II)″ 线性无关，故（临界定理）$\beta\leftarrow(I)''$，所以$(I)\leftarrow(I)''$所以$(I)''$是极大无关组。

P155.T8

证明：

设$\alpha_1,\alpha_2,\cdots,\alpha_s$（I），$\alpha_{i1},\alpha_{i2},\cdots,\alpha_{ir}$ (I)′，及(I)的一个极大无关组$\alpha_{i1},\alpha_{i2},\cdots,\alpha_{ir}$ (I)″，已知$(I)\leftarrow(I)'$，故有

$$(I)'\rightleftarrows(I)\rightleftarrows(I)''$$

所以取$(I)'$的极大无关组$\alpha_{k1},\alpha_{k2},\ldots,\alpha_{kt}$(I)″，则t ≤r且$(I)''\rightleftarrows(I)'\rightleftarrows(I)''$，那么$(I)'''\rightarrow(I)''$由于$(I)''$有r个向量且线性无关，所以（由定理 2 推论 1）r ≤t，即r=t，故$(I)'''=(I)'$，$(I)'$线性无关。

$(I)'$是(I)的一个极大无关组。

P155.T9

证明：设(I)的一个线性无关组(I)′

1° 逐个检查(I)中的向量α_i

2° a、若$\alpha_i\leftarrow(I)'$，则去掉α_i，检查下一个α

b、若存在$\alpha_i \not\leftarrow (I)'$，则添加$\alpha_i$到(I)′ 中将(I)′ 扩充为(I)″，回到检查第 1 个向量，重复 1°、2°

若干步后（∵有限步后，任意n+1 个n维向量也相关，必含停止），得到$(I)',(I)'',\ldots(I)^{(k-1)}$, $(I)^{(k)}$

而$(I)^{(k)}$不得再扩大，于是$(I)^{(k)}$是一个极大无关组，是$(I)'\subseteq(I)^{(k)}$。

P155.T10

1）解：∵α_1与α_2的分量不成比例，故α_1与α_2线性无关

2）解：考虑$\alpha_1,\alpha_2,\alpha_3$ ∵$3\alpha_1+\alpha_2=\alpha_3$ 去掉α_3

考虑$\alpha_1,\alpha_2,\alpha_4$,取它们的后三个分量$\begin{vmatrix}-1 & 2 & 4\\ 3 & 1 & 2\\ 1 & 2 & 0\end{vmatrix}=28\neq0$，∴增加一个分量后仍然线性无关。

即$\alpha_1, \alpha_2, \alpha_4$线性无关

再考虑$\alpha_1, \alpha_2, \alpha_4, \alpha_5$,因为分量行列式

$$\begin{vmatrix} 1 & -1 & 2 & 4 \\ 0 & 3 & 1 & 2 \\ 1 & -1 & 2 & 0 \\ 2 & 1 & 5 & 6 \end{vmatrix} = 0$$

即$\alpha_5=\alpha_1+\alpha_2+\alpha_4$　所以它的极大线性无关组是$\alpha_1, \alpha_2, \alpha_4$

P155.T11

1）解：

$$\begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{pmatrix} = \begin{array}{c} \begin{pmatrix} 6 & 4 & 1 & -1 & 2 \\ 1 & 0 & 2 & 3 & -4 \\ 1 & 4 & -9 & -16 & 22 \\ 7 & 1 & 0 & -1 & 3 \end{pmatrix} \end{array} \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \end{array} \to \begin{pmatrix} 1 & 0 & 2 & 3 & -4 \\ 0 & 4 & -11 & -19 & 26 \\ 0 & 4 & -11 & -19 & 26 \\ 0 & 1 & -14 & -22 & 31 \end{pmatrix} \begin{array}{c} 2 \\ 1 \\ 3 \\ 4 \end{array} \to \begin{pmatrix} 1 & 0 & 2 & 3 & -4 \\ 0 & 1 & -14 & -22 & 31 \\ 0 & 0 & 45 & * & * \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{array}{c} 2 \\ 4 \\ 1 \\ 3 \end{array}$$

$\therefore$秩$(\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5)=3$，且$\alpha_2, \alpha_3, \alpha_4$为一个极大无关组。

　$\therefore$秩(A)=5

2）解：略

P156.T12

证：　设$(I)'$为$(II)''$分别为(I)、(II)的极大无关组，则有

$$(I)' \rightleftarrows (I) \leftarrow (II) \rightleftarrows (II)'$$

设$(I)'$含r个向量，$(II)'$含七个向量，因为$(I)'$线性无关，且$(I)' \leftarrow (II)'$，所以r≤t，即秩(I)≤秩(II)

P156.T13

证明：设$\alpha_{i1},\alpha_{i2},\cdots,\alpha_{ir}$为$\alpha_1,\alpha_2,\cdots,\alpha_n$的极大线性无关组则得下面表示序列

$$\alpha_{i1}, \alpha_{i2}, \cdots, \alpha_{ir} \rightleftarrows \alpha_1, \alpha_2, \cdots, \alpha_n \to \varepsilon_1, \varepsilon_2, \cdots, \varepsilon_n$$

因为单位向量组$\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_n$线性无关，由（定理 2 推论），得n ≤ r故$\alpha_{i1},\alpha_{i2},\ldots,\alpha_{ir}$为$\alpha_1,\alpha_2,\cdots,\alpha_n$本身，即证得$\alpha_1,\alpha_2,\cdots \alpha_n$,线性无关。

P156.T14

证明：略

P156.T15

证明："⇐"若系数行列式$|a_{ij}|\neq 0$，则由Cramer法则，对任何常数$b_1,b_2,\ldots,b_n$有唯一解。

"⇒" $A=\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ a_{12} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}$ 则原方程组为 $x_1\beta_1+x_2\beta_2+\cdots+x_n\beta_n=b$

其中$\beta_2,\beta_3,\ldots,\beta_n$为A的列向量组，∵对任何 $b=\begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{pmatrix}$ 都有解。

依次定 $b=\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n$，则得

$$\beta_1,\beta_2,\cdots,\beta_n\to\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n$$

从而$\beta_2,\beta_3,\ldots,\beta_n$线性无关，列秩 (A)=n，即秩(A)=n，由定理 5，$|A|\neq 0$

P156.T16

证明： 设$\alpha_1,\alpha_2,\cdots,\alpha_r$(I)及$\alpha_1,\cdots\alpha_r,\alpha_{r+1},\cdots,\alpha_s$(II)，且秩(I)=秩(II)=t，设$\alpha_{i1},\alpha_{i2},\cdots,\alpha_{it}$(III)为(I)的极大无在组$\alpha_{i1},\alpha_{i2},\cdots,\alpha_{it}$(IV)为(II)的极大无关组，那么，$(III)\rightleftarrows(I)\leftarrow(II)\rightleftarrows(IV)$

任取(II)中一个向量β，组成$\alpha_{i1},\alpha_{i2},\cdots,\alpha_{it}$，β—(V)，则$(V)\leftarrow(II)\leftarrow(IV)$，因为（IV）只有七个向量，所以（V）线性相关，而（III）线性无关。

所以$\beta\leftarrow(III)$即$(II)\leftarrow(III)$ $\quad\therefore(II)\rightleftarrows(III)$

$\therefore(I)\rightleftarrows(III)\rightleftarrows(II)$ （I）与（II）等价

P156.T17

证明： ∵$\beta_1=\alpha_2+\ldots+\alpha_r$，$\beta_2=\alpha_1+\alpha_3+\ldots+\alpha_r,\cdots,\beta_r=\alpha_1+\ldots+\alpha_{r-1}$

$$\therefore\beta_1,\beta_2,\cdots,\beta_r\to\alpha_1,\alpha_2,\cdots,\alpha_r$$

令 $r=\beta_1+\beta_2+\cdots+\beta_r=(r-1)(\alpha_1+\alpha_2+\cdots+\alpha_r)$

$\therefore\alpha_i=\dfrac{1}{r-1}r-\beta_i$ 即α_i可以$\beta_1,\beta_2,\ldots,\beta_r$线性表示

$\therefore\beta_1,\beta_2,\cdots,\beta_r\rightleftarrows\alpha_1,\alpha_2,\cdots,\alpha_r$ 秩必相同

P156.T18

① $A\to\begin{pmatrix}1&1&0&1&-1\\0&-1&-1&1&1\\0&0&0&0&3\\0&0&-4&0&2\end{pmatrix}\to\begin{pmatrix}1&1&0&1&-1\\0&-1&-1&1&1\\0&0&-4&0&2\\0&0&0&0&3\end{pmatrix}$ ∴秩(A)=4

② $A\to\begin{pmatrix}1&-1&2&1&0\\0&0&0&-4&0\\0&3&0&-4&1\\0&3&0&0&1\end{pmatrix}\to\begin{pmatrix}1&-1&2&1&0\\0&3&0&0&1\\0&0&0&-4&0\\0&0&0&-4&0\end{pmatrix}\to\begin{pmatrix}1&-1&2&1&0\\0&3&0&0&1\\0&0&0&-4&0\\0&0&0&0&0\end{pmatrix}$ ∴ 秩(A)=3

③ $A\to\begin{pmatrix}6&104&21&9&17\\7&6&3&4&0\\0&0&0&0&0\\0&0&0&0&0\end{pmatrix}=B$ 显然B中有2阶子式不等于0 且所有3阶子式等于0 ∴秩(B)=2 $\text{秩}(A)=2$

④ $A\to\begin{pmatrix}1&0&0&1&4\\0&1&0&2&5\\0&0&1&3&6\\0&2&3&13&28\\0&5&6&28&61\end{pmatrix}\to\begin{pmatrix}1&0&0&1&4\\0&1&0&2&5\\0&0&1&3&6\\0&0&3&9&18\\0&0&6&18&36\end{pmatrix}\to\begin{pmatrix}1&0&0&1&4\\0&1&0&2&5\\0&0&1&3&6\\0&0&0&0&0\\0&0&0&0&0\end{pmatrix}$ ∴秩(A)=3

⑤

$$A\to\begin{pmatrix}1&0&1&0&0\\0&1&-1&0&0\\0&1&1&0&0\\0&0&1&1&0\\0&1&0&1&1\end{pmatrix}\to\begin{pmatrix}1&0&1&0&0\\0&1&-1&0&0\\0&0&-2&0&0\\0&0&1&1&0\\0&0&1&1&1\end{pmatrix}\to\begin{pmatrix}1&0&1&0&0\\0&1&-1&0&0\\0&0&-2&0&0\\0&0&0&1&0\\0&0&0&1&1\end{pmatrix}\to\begin{pmatrix}1&0&1&0&0\\0&1&-1&0&0\\0&0&-2&0&0\\0&0&0&1&0\\0&0&0&0&1\end{pmatrix}$$

∴秩(A)=5

P157. T19

①∵ $\begin{vmatrix}\lambda&1&1\\1&\lambda&1\\1&1&\lambda\end{vmatrix}=(\lambda+2)(\lambda-1)^2$；

∴当$\lambda\neq1$时，有唯一解。$x_1=\dfrac{-(\lambda+1)}{\lambda+2},x_2=\dfrac{1}{\lambda+2},x_3=\dfrac{(\lambda+1)^2}{\lambda+2}$。

∴当λ=-2 时，三个方程解相加，得 0=3（无解）。

∴当λ=1 时，变为一个方程$x_1+x_2+x_3=1$ 即$x_1=1-x_2-x_3$. x_2 x_3任取。

②∵系数解列式$\begin{vmatrix}\lambda+3 & 1 & 2\\ \lambda & \lambda-1 & 1\\ 3(\lambda+1) & \lambda & a+3\end{vmatrix}=\lambda^3-\lambda^2=\lambda^2(\lambda-1)$。

而$\lambda\neq$0 且$\lambda\neq$1 时，有唯一解：（用Craner法则）

$$x_1=\frac{\lambda^3+3^{\lambda 2}-15\lambda+9}{a^2(\lambda-1)},x_2=\frac{\lambda^3+12\lambda-9}{\lambda^2(\lambda-1)},x_3=\frac{-4\lambda^2+3\lambda^2+12\lambda-9}{\lambda^2(\lambda-1)}$$。

而当λ=0 时为$\begin{cases}3x_1+x_2+2x_3=0\\ -x_2+x_3=0\\ 3x_1+3x_3=3\end{cases}$ ①式+②式-③式得 0=-3，矛盾。

当λ=1 时为$\begin{cases}4x_1+x_2+2x_3=1\\ x_1+\cdots+x_3=2\\ 6x_1+x_2+4x_3=3\end{cases}$①式+②式两倍-③式得 0=2，矛盾。

③系数行列式$\begin{vmatrix}a & 1 & 1\\ 1 & b & 1\\ 1 & 2b & 1\end{vmatrix}=b(1-a)$。

当$\lambda\neq$0 且a≠1 时，有唯一解。$x_1=\frac{1-2b}{b(1-a)},x_2=\frac{1}{b},x_3=\frac{4b-2ab-1}{b(1-a)}$。

若 b=0, 则②式-③式得 0=-1。矛盾。

若b≠0 而a=1。化为$\begin{cases}x_1+x_2+x_3=4\\ x_1+bx_2+x_3=3\\ x_1+2bx_2+x_3=4\end{cases}$

①-③得（1-2b）x_2=0

①-②得（1-b）x_2=1

∴ $x_2\neq 0$又与$(1-2b)=0$ 即$b=\frac{1}{2}.\left(b\neq\frac{1}{2}\text{则矛盾无解}\right)$

此时化为$\begin{cases}x_1+x_2+x_3=4\\ x_1+\frac{1}{2}x_2+x_3=3\\ x_1+x_2+x_3=4\end{cases}$即$\begin{cases}x_1+x_2+x_3=4\\ x_2=2\end{cases}$即$\begin{cases}x_1=2-x_3\\ x_2=2\end{cases}$ x_3任意值

P157.T20、

1) $\begin{pmatrix}1 & 1 & 1 & 1 & 1\\ 3 & 2 & 1 & 1 & -3\\ 0 & 1 & 2 & 2 & 6\\ 5 & 4 & 3 & 3 & -1\end{pmatrix}\to\begin{pmatrix}1 & 1 & 1 & 1\\ 0 & -1 & -2 & -6\\ 0 & 1 & 2 & -6\\ 0 & -1 & -2 & -6\end{pmatrix}\to\begin{pmatrix}1 & 0 & -1 & -1 & -5\\ 0 & 1 & 2 & 2 & 6\\ 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0\end{pmatrix}$

即 x_3,x_4,x_5为自由未知量.

$$(1,0,0)\qquad \eta_1=(1,-2,1,0,0)$$
$$(0,1,0)\qquad \eta_2=(1,-2,0,1,0)$$
令$\left(x_3,x_4,x_5\right)=(0,0,1)$ 得：$\eta_3=(1,-2,0,0,1)$

2）

$$\begin{pmatrix}1&1&0&-3&-1\\1&-1&2&-1&0\\4&-2&6&3&-4\\2&4&-2&4&-7\end{pmatrix}\to\begin{pmatrix}1&1&0&-3&-1\\0&-2&2&2&1\\0&-6&6&15&0\\0&2&-2&10&-5\end{pmatrix}\to\begin{pmatrix}1&1&0&-3&-1\\0&-2&2&2&1\\0&0&0&9&-3\\0&0&0&12&-4\end{pmatrix}$$

$$\to\begin{pmatrix}1&0&1&-2&-\frac{1}{2}\\0&1&-1&-1&-\frac{1}{2}\\0&0&0&1&-\frac{1}{3}\\0&0&0&0&0\end{pmatrix}\to\begin{pmatrix}1&0&1&0&-\frac{7}{6}\\0&1&-1&0&-\frac{5}{6}\\0&0&0&1&-\frac{1}{3}\\0&0&0&0&0\end{pmatrix}$$

即x_1,x_2,x_5为基本，x_3,x_4为自由未知量。

$$(x_3,x_4)=(1,0)\qquad \eta_1=(-1,1,1,0,0)$$
令$(x_3,x_4)=(0,1)$，得 $\eta_2=(\frac{7}{6},\frac{5}{6},0\frac{1}{3},1)$。

即基础解系为（$-1,1,1,0,-2$）和（$7,5,0,2,6$）

4）

$$\begin{pmatrix}1&-2&1&-1&1\\2&1&-1&2&-3\\3&-2&-1&1&-2\\2&-5&1&-2&2\end{pmatrix}\to\begin{pmatrix}1&-2&1&-1&1\\0&5&-3&4&-5\\0&4&-4&4&-5\\0&-1&-1&0&0\end{pmatrix}\to\begin{pmatrix}1&0&3&-1&1\\0&1&1&0&0\\0&0&-8&4&-5\\0&0&-8&4&-5\end{pmatrix}$$

$$\to\begin{pmatrix}1&0&0&+1/2&-7/8\\0&1&0&1/2&-5/8\\0&0&1&-1/2&5/8\\0&0&0&0&0\end{pmatrix}\text{即}\begin{cases}x_1=-\frac{1}{2}x_4+\frac{7}{8}x_5\\x_2=-\frac{1}{2}x_4+\frac{7}{8}x_5\\x_3=-\frac{1}{2}x_4+\frac{7}{8}x_5\end{cases}$$

令$\left(x_4,x_5\right)=\left(1.0\right)\left(0.1\right)$得基础解系$\begin{cases}y_1=\left(-\frac{1}{2},-\frac{1}{2},\frac{1}{2},1,0\right)\\y_2=\left(\frac{7}{8},\frac{5}{8},-\frac{5}{8},0,1\right)\end{cases}$

P157.T22 $\begin{pmatrix} 1 & 1 & 1 & 1 & 1 \\ 3 & 2 & 1 & -3 & a \\ 0 & 1 & 2 & 6 & 3 \\ 5 & 4 & 3 & -1 & b \end{pmatrix} \to$

$$\begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & -1 & -2 & -2 & -6 & a-3 \\ 0 & 1 & 2 & 2 & 6 & 3 \\ 0 & -1 & -2 & -2 & -6 & b-5 \end{pmatrix} \to \begin{pmatrix} 1 & 0 & -1 & -1 & -5 & -2 \\ 0 & 1 & 2 & 2 & 6 & 3 \\ 0 & 0 & 0 & 0 & 0 & a \\ 0 & 0 & 0 & 0 & 0 & b-2 \end{pmatrix}$$

由于有解$\Leftrightarrow$秩（系）=秩（增）故有解$\Leftrightarrow$ a=0, b=2.

此时，x_1, x_2为基础未知量。特解为r_0=(-2, 3, 0, 0, 0)

x_3, x_4, x_r为自由未知量，依次取

（x_3, x_4. x_r）=(1, 0, 0) $\qquad$ η_1=(1, -2, 1, 0, 0)

（x_3, x_4. x_r）=(0, 1, 0) $\qquad$ 得 $\qquad$ η_2=(1, -2, 0, 1, 0)

（x_3, x_4. x_r）=(0, 0, 1) $\qquad$ η_3=(5, -6, 0, 0, 1)

通解为 $r_0+k_1\eta_1+k_2\eta_2+k_3\eta_3$（$k_1$, k_2, k_3为任意常数。）

P158.T23

增广矩阵$\begin{pmatrix} 1 & -1 & 0 & 0 & 0 & a_1 \\ & 1 & -1 & 0 & 0 & a_2 \\ & & & -1 & 0 & a_3 \\ & & & 1 & -1 & a_4 \\ -1 & 0 & 0 & 0 & 1 & a_5 \end{pmatrix} \to \begin{pmatrix} 1 & -1 & 0 & 0 & 0 & a_1 \\ 0 & 1 & -1 & 0 & 0 & a_2 \\ & & 1 & -1 & 0 & a_3 \\ & & & 1 & -1 & a_4 \\ 0 & 0 & 0 & 0 & 0 & a_1+a_2+a_3+a_4+a_5 \end{pmatrix}$

因为系数矩阵秩为 4。增广矩阵秩为 5 $\Leftrightarrow \sum_{i=1}^{5} ai \neq 0$

秩为 4 $\Leftrightarrow \sum_{i=1}^{5} a_i = 0$

故由有解判别定理，方程组有解$\Leftrightarrow$秩(系)=秩(增) $\Leftrightarrow \sum_{i=1}^{5} a_i = 0$

有解时，即 $\sum_{i=1}^{5} ai=0$ 。矩阵化为最简阶梯→ $\begin{pmatrix} 1 & 0 & 0 & -1 & a_1+a_2+a_3+a_4 \\ 0 & 1 & 0 & -1 & a_2+a_3+a_4 \\ 0 & 0 & 1 & -1 & a_3+a_4 \\ 0 & 0 & 0 & -1 & a_4 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$

特解 $r_0=(a_1+a_2+a_3+a_4,\ a_2+a_3+a_4,\ a_3+a_4, 0)$。

导出组基础系（只有一个自由求知数 $x_5=1$）为 η=（1，1，1，1，1）。

所以方程组的通解为 $r_0+k\eta$。k为任意的数。

P158.T24

设 η_1，$\eta_2,\cdots\eta_s$ 是某齐次方程组的基础解系，而 ξ_1，$\xi_2\cdots\xi_t$ 是方程组的线形无关解组。则 η_1，$\eta_2,\cdots\eta_s \Leftrightarrow \xi_1$，$\xi_2\cdots\xi_t$。由于等价且都线形无关，必有s = t. 由传递性，方程的任一解可由 η_1，$\eta_2,\cdots\eta_s$ 线形表示，也可由 ξ_1，$\xi_2\cdots\xi_t$ 线形表示。ξ_1，$\xi_2\cdots\xi_t$ 也是基础解系。

P158.T25

由于秩（系）=r. 故基础解系会$n-r$个向量 η_1，$\eta_2\cdots\eta_{n-r}$（$r<n$ ）

而它们任意$n-r$解 ζ_1，$\zeta_2\cdots\zeta_{n-r}$. 如果线性无关。则由（补 6，P157）的证明方法：（见 3.41.6.*）。秩（η_1，$\eta_2\cdots\cdots\eta_{n-r}$）=秩（$\zeta_1$，$\zeta_2\cdots\cdots\zeta_{n-r}$）=$n-r$。且 ζ_1，$\zeta_2\cdots\cdots\zeta_{n-r}\leftarrow\eta_1$，$\eta_2\cdots\cdots\eta_{n-r}$。故，$\zeta_1$，$\zeta_2\cdots\zeta_{n-r}\Leftrightarrow\eta_1\ \eta_2\cdots\cdots\eta_{n-r}$（再由上题（24 题）知向量 ζ_1，$\zeta_2\cdots\cdots\zeta_{n-r}$也为方程组的基础解系。

P158.T26

证明：设 $\eta_v=(k_{v1},\ k_{v2},\cdots k_{vn})$ （v=1，2，…t）为方程组 $\sum_{j=1}^{n} a_{ij}x_j=b_j(j=1,2,\cdots s)$ 的解，

即必有 $\sum_{j=1}^{n} a_{ij}k_{vj}=b_j$ $\begin{pmatrix} v=1\cdots t \\ i=1\cdots s \end{pmatrix}$，那么 $\eta=\sum_{v=1}^{n} u_v\eta_v$ 代入方程组得 $\sum_{j=1}^{n} a_{ij}\sum_{v=1}^{t} u_v k_{vj} = \sum_{v=1}^{t}(\sum_{j=1}^{n} a_{ij}k_{vj})\ u_v = \sum_{v=1}^{t} b_i u_v = b_i\sum_{v=1}^{t} u_v = b_i$（由已知条件 $\sum_{v=1}^{t} u_v=1$）

$\therefore$ $\eta=\sum_{v=1}^{n} u_v\eta_v$ 是方程的解。

此题反过来也成立，即

若 $\sum_{v=1}^{t} u_v\eta_v$ 为非齐次方程的解，且 η_v 也是解，则必有 $\sum_{v=1}^{t} u_v=1$ 。

P158.T27

$$\begin{vmatrix} a_0, a_1 \cdots a_n \\ a_0 \cdots a_n \\ a_0 \cdots a_n \\ b_0 \cdots b_m \\ b_0 \cdots b_m \\ b_0 \cdots b_m \end{vmatrix} = (-1)^m \begin{vmatrix} b_0, b_1 \cdots b_n \\ a_0, a_1 \cdots a_n \\ a_0 \cdots a_n \\ a_0 \cdots a_n \\ b_0 \cdots b_m \\ b_0 \cdots b_m \end{vmatrix} = (-1)^m \cdots = (-1)^{mn} \begin{vmatrix} b_0, b_r \cdots b_m \\ b_0 \cdots b_m \\ a_0 \cdots a_n \\ a_0 \cdots a_m \end{vmatrix} = (-1)^{mn} R(g.f)$$

R（f·g）= $其中 n = \partial\big(f(x)\big) \quad m = \partial\big(g(x)\big)$

158.T28

①

$$R.\big(f.g\big) = \begin{vmatrix} 5 & -6x & 5x^2-16 & 0 \\ 0 & 5 & -6x & 5x^2-16 \\ 1 & -x-1 & 2x^2-x-4 & 0 \\ 0 & 1 &]=-x-1 & 2x^2-x-4 \end{vmatrix} = \begin{vmatrix} 0 & -x+5 & 0 \\ 0 & 0 & -5x^2+5x+4 \\ 1 & -x-1 & \\ 0 & 1 & 2x^2-x-4 \end{vmatrix}$$

$=(-1)^{3+1}\begin{vmatrix} 0 & -6x^2+9x+9 & (2x^2-x-4) \\ 0 & -x+5 & -5x^2+5x+4 \\ 1 & -x-1 & 2x^2-x-4 \end{vmatrix}$ 直接展开方程相加

$=32x^4-96x^3+96x-64$。$=32(x^4-3x^3+x^2+3x-2)=32(x^2-1)(x^2-3x+2)$

$=32(x-1)^2(x+1)(x-2)$

有 4 个解是 $x_1=x_2=1$，$x_3=2$，$x_4=-1$。

用 $x=1$ 代入在方程组得 $\begin{cases} 5y^2-6y-11=0 \\ y^2-2y-3=0 \end{cases}$ 有公共解 $y=-1$，即 $\begin{cases} x=1 \\ y=-1 \end{cases}$

用 $\gamma=2$ 代入在方程组得 $\begin{cases} 5y^2-12y+4=0 \\ y^2-3y-3=0 \end{cases}$ 有公共解 $y=2$，即 $\begin{cases} \gamma=2 \\ y=-1 \end{cases}$

用 $x=-1$ 代入在方程组得 $\begin{cases} 5y^2+6y-11=0 \\ y^2-1=0 \end{cases}$ 有公共解 $y=1$，即 $\begin{cases} x=-1 \\ y=1 \end{cases}$

即得到三组解 $\begin{cases} x=1 \\ y=-1 \end{cases} \begin{cases} \gamma=2 \\ y=-1 \end{cases} \begin{cases} x=-1 \\ y=1 \end{cases}$

第四章　矩阵练习题参考答案

P197.T1

①解: $AB=\begin{pmatrix}6 & 2 & -2\\ 6 & 1 & 0\\ 8 & -1 & 2\end{pmatrix}$ $BA=\begin{pmatrix}1 & 1 & -1\\ 2 & -1 & 0\\ 1 & 0 & 1\end{pmatrix}\begin{pmatrix}3 & 1 & 1\\ 2 & 1 & 2\\ 1 & 2 & 3\end{pmatrix}=\begin{pmatrix}4 & 0 & 0\\ 4 & 1 & 0\\ 4 & 3 & 4\end{pmatrix}$

∴ $AB-BA=\begin{pmatrix}2 & 2 & -2\\ 2 & 0 & 0\\ 4 & -4 & -2\end{pmatrix}$

②解: $AB=\begin{pmatrix}a+b+c & a^2+b^2+c^2 & ac+b^2+ac\\ a+b+c & ac+b^2+ac & a^2+b^2+c^2\\ 3 & a+b+c & a+b+c\end{pmatrix}$

$$BA=\begin{pmatrix}1 & a & c\\ 1 & b & b\\ 1 & c & a\end{pmatrix}\begin{pmatrix}a & b & c\\ c & b & a\\ 1 & 1 & 1\end{pmatrix}=\begin{pmatrix}a+ac+c & b+ab+c & c+a^2+c\\ a+bc+b & b+b^2+b & c+ab+b\\ a+c^2+a & b+bc+a & c+ac+a\end{pmatrix}$$

$$\therefore AB-BA=\begin{pmatrix}b-ac & a^2+b^2+c^2-b-ab-c & b^2-a^2+2ac-2c\\ c-bc & 2(ac-b) & a^2+b^2+c^2-b-ab-c\\ 3-2a-c^2 & c-bc & b-ac\end{pmatrix}$$

P198.T 2

①解: $\begin{pmatrix}3 & 1 & 1\\ 3 & 1 & 0\\ 0 & 1 & 2\end{pmatrix}^2=\begin{pmatrix}3 & 1 & 1\\ 3 & 1 & 0\\ 0 & 1 & 2\end{pmatrix}\begin{pmatrix}3 & 1 & 1\\ 3 & 1 & 0\\ 0 & 1 & 2\end{pmatrix}=\begin{pmatrix}12 & 5 & 5\\ 12 & 4 & 3\\ 3 & 3 & 4\end{pmatrix}$

②解: $\begin{pmatrix}3 & 2\\ -4 & -2\end{pmatrix}^5=\begin{pmatrix}3 & 2\\ -4 & -2\end{pmatrix}^3\begin{pmatrix}1 & 2\\ -4 & -4\end{pmatrix}=\begin{pmatrix}-5 & -2\\ 4 & 0\end{pmatrix}\begin{pmatrix}1 & 2\\ -4 & -4\end{pmatrix}=\begin{pmatrix}3 & -2\\ 4 & 8\end{pmatrix}$

④解: ∵ $\begin{pmatrix}\cos\varphi & -\sin\varphi\\ \sin\varphi & \cos\varphi\end{pmatrix}\begin{pmatrix}\cos\theta & -\sin\theta\\ \sin\theta & \cos\theta\end{pmatrix}=\begin{pmatrix}\cos(\varphi+\theta) & -\sin(\varphi+\theta)\\ \sin(\varphi+\theta) & \cos(\varphi+\theta)\end{pmatrix}$

∴ $\begin{pmatrix}\cos\varphi & -\sin\varphi\\ \sin\varphi & \cos\varphi\end{pmatrix}^n=\begin{pmatrix}\cos n\varphi & -\sin n\varphi\\ \sin n\varphi & \cos n\varphi\end{pmatrix}$

5 解:

$$(2,3,-1)\begin{pmatrix}1\\-1\\-1\end{pmatrix}=2-3+1=0$$

$$\begin{pmatrix}1\\-1\\-1\end{pmatrix}(2,3,-1)=\begin{pmatrix}2&3&-1\\-2&-3&1\\-2&-3&1\end{pmatrix}$$

6 解:

原式= $$(x,y,1)\begin{pmatrix}a_{11}x+a_{12}y+b_1\\a_{12}x+a_{22}y+b_2\\b_1x+b_2y+c\end{pmatrix}=a_{11}x^2+2a_{12}xy+a_{22}y^2+2b_1x+2b_1y+c$$

7 解: $$A=\begin{pmatrix}1&-1&-1&-1\\-1&1&-1&-1\\-1&-1&1&-1\\-1&-1&-1&1\end{pmatrix}\quad A^2=\begin{pmatrix}4&0&0&0\\0&4&0&0\\0&0&4&0\\0&0&0&4\end{pmatrix}\quad\therefore\ A^n=\begin{cases}2^nE & n=2k\text{时}\\2^{n-1}A & n=2k+1\text{时}\end{cases}$$

8 解: $$\begin{pmatrix}\lambda&1&0\\0&\lambda&1\\0&0&\lambda\end{pmatrix}^2=\begin{pmatrix}\lambda^2&2\lambda&1\\0&\lambda^2&2\lambda\\0&0&\lambda\end{pmatrix},$$ 而

$$\begin{pmatrix}\lambda^k&c_k^1\lambda^{k-1}&c_k^2\lambda^{k-2}\\0&\lambda^k&c_k^1\lambda^{k-1}\\0&0&\lambda^k\end{pmatrix}\begin{pmatrix}\lambda&1&0\\0&\lambda&1\\0&0&\lambda\end{pmatrix}=\begin{pmatrix}\lambda^{k+1}&c_{k+1}^1\lambda^k&c_{k+1}^2\lambda^{k-1}\\0&\lambda^{k+1}&c_{k+1}^1\lambda^k\\0&0&\lambda^{k+1}\end{pmatrix}$$

$\therefore$ $$\begin{pmatrix}\lambda&1&0\\0&\lambda&1\\0&0&\lambda\end{pmatrix}^n=\begin{pmatrix}\lambda^n&c_n^1\lambda^{n-1}&c_n^2\lambda^{n-2}\\0&\lambda^n&c_n^1\lambda^{n-1}\\0&0&\lambda^n\end{pmatrix}=\begin{pmatrix}\lambda^n&n\lambda^{n-1}&\frac{1}{2}n(n-1)\lambda^{n-2}\\0&\lambda^n&n\lambda^{n-1}\\0&0&\lambda^n\end{pmatrix}$$

P198.T3

① $$A^2=\begin{pmatrix}2&1&1\\3&1&2\\1&-1&0\end{pmatrix}^2=\begin{pmatrix}8&2&4\\11&2&5\\-1&0&-1\end{pmatrix}$$

$$\therefore f(A)=A^2-A-E=\begin{pmatrix}6&1&3\\8&0&3\\-2&2&-1\end{pmatrix}-E=\begin{pmatrix}5&1&3\\8&-1&3\\-2&2&-2\end{pmatrix}$$

② $$A^2=\begin{pmatrix}2&-1\\-3&3\end{pmatrix}^2=\begin{pmatrix}7&-5\\-15&12\end{pmatrix}$$

$\therefore f(A)=A^2-5A+3E=A^2-\begin{pmatrix}7&-5\\-15&12\end{pmatrix}=0$

P199.T4.

①设 $X=\begin{pmatrix}a&b\\c&d\end{pmatrix},AX=\begin{pmatrix}a+c&b+d\\c&d\end{pmatrix},XA=\begin{pmatrix}a&a+b\\c&c+d\end{pmatrix},$

由 $AX=XA\Rightarrow c=0$，$a+b=b+d\Rightarrow a=d$

$\therefore X=\begin{pmatrix}a&b\\0&a\end{pmatrix}$ a,b 任取。

②$\because XA=AX\Leftrightarrow X(A-E)=(A-E)X.$ $\overline{A}=A-E=\begin{pmatrix}0&0&0\\0&0&2\\3&1&1\end{pmatrix}$

设$X=\begin{pmatrix}x_{11}&x_{12}&x_{13}\\x_{21}&x_{22}&x_{23}\\x_{31}&x_{32}&x_{33}\end{pmatrix}$, $X\overline{A}=\begin{pmatrix}3x_{13}&x_{13}&2x_{12}+x_{13}\\3x_{23}&x_{23}&2x_{22}+x_{23}\\3x_{33}&x_{33}&2x_{32}+x_{33}\end{pmatrix}$,

$$\overline{A}X=\begin{pmatrix}0&0&0\\2x_{31}&2x_{32}&2x_{33}\\3x_{11}+x_{21}+x_{31}&3x_{12}+x_{22}+x_{32}&3x_{13}+x_{23}+x_{33}\end{pmatrix}$$

$\therefore x_{12}=x_{13}=0$

令 $\begin{matrix}x_{21}=3a\\x_{22}=b\\x_{23}=2c\end{matrix}\Rightarrow\begin{matrix}x_{31}=3c\\x_{32}=c\\x_{33}=b+c\end{matrix}\Rightarrow\begin{matrix}x_{11}=b+c-a-c\\x_{22}=0\\x_{13}=0\end{matrix}$ $\therefore x=\begin{pmatrix}b-a&0&0\\3a&b&2c\\3c&c&b+c\end{pmatrix}$

③同样设 $X=\begin{pmatrix}x_{11}&x_{12}&x_{13}\\x_{21}&x_{22}&x_{23}\\x_{31}&x_{32}&x_{33}\end{pmatrix}$, $AX=\begin{pmatrix}x_{25}&x_{22}&x_{23}\\x_{31}&x_{32}&x_{33}\\0&0&0\end{pmatrix}$, $XA=\begin{pmatrix}0&x_{11}&x_{12}\\0&x_{21}&x_{22}\\0&x_{31}&x_{32}\end{pmatrix}$

$\therefore x_{21}=x_{31}=x_{32}=0,x_1=x_{22}=x_{33},x_{23}=x_{12}\therefore x=\begin{pmatrix}x_{11}&x_{12}&x_{13}\\0&x_{11}&x_{12}\\0&0&x_{11}\end{pmatrix}$

P199.T5

设 $X=\begin{pmatrix}x_{11}&x_{12}&\cdots&x_{1n}\\x_{21}&x_{22}&\cdots&x_{2n}\\&\cdots&\cdots&\\x_{n1}&x_{n2}&\cdots&x_{nn}\end{pmatrix}$ $\because AX=XA$

左边i行j列的元为 a_ix_{ij}

右边i行j列的元素 $x_{ij}a_j$

$\therefore i \neq j$, $a_i x_{ij} = a_j x_{ij} \Rightarrow \left(a_i - a_j\right) x_{ij} \Rightarrow x_{ij} = 0$ $(\because a_i \neq a_j)$

$$\therefore X = \begin{pmatrix} x_{11} & & & \\ & x_{22} & & \\ & & \cdots & \\ & & & x_{nn} \end{pmatrix}$$ 只是对角矩阵

P199.T6

$$A = \begin{pmatrix} a_1 E_{n1} & & & \\ & a_2 E_{n2} & & \\ & & \cdots & \\ & & & a_r E_{nr} \end{pmatrix}$$ $(n_1 + n_2 + \cdots + n_r = n)$

$$令 X = \begin{pmatrix} X_{11} & X_{12} & \cdots & X_{1r} \\ X_{21} & X_{22} & \cdots & X_{2r} \\ & \cdots & \cdots & \\ X_{r1} & X_{r2} & \cdots & X_{rr} \end{pmatrix}$$

且 X_{ij}为$n_i \times n_j$型才能$AX = XA$分块相乘,应有

$$\left.\begin{matrix} 左边AX第i块行j块列为a_i E_{ni} \cdot X_{ij} = a_i X_{ij} \\ 右边XA第i块行j块列为X_{ij} \cdot a_j E_{nj} = a_j X_{ij} \end{matrix}\right\} \because i \neq j . a_i \neq a_j$$

$\therefore$ $i \neq j$时, $x_{ij} = 0$. $\therefore$ $$X = \begin{pmatrix} X_{11} & & \cdots & \\ & X_{22} & \cdots & \\ & \cdots & \cdots & \\ & & \cdots & X_{rr} \end{pmatrix}$$为与A同类型的准对角矩阵

P199.T7

①设 $A = \left(a_{ij}\right)_{nxn}$. $$AE_{12} = \begin{pmatrix} 0 & a_{11} & \cdots 0 \\ 0 & a_{21} & \cdots 0 \\ 0 & a_{31} & \cdots 0 \\ 0 & \vdots & \cdots 0 \\ 0 & a_n & \cdots 0 \end{pmatrix}, \quad E_{12} A = \begin{pmatrix} a_{21} & a_{22} & \cdots & a_{2n} \\ 0 & \ddots & & 0 \\ \vdots & & \ddots & \\ 0 & & & 0 \end{pmatrix}$$

$\therefore$A的第一列 $a_{11} = a_{22}$, 其余$a_{k1} = 0\left(k > 1\right)$

A的第二行 $a_{22} = a_{11}$, 其余$a_{2S} = 0\left(s \neq 2\right)$

$$A = \begin{pmatrix} a_{11} & & & * & & \\ 0 & a_{11} & 0 & \cdots & \cdots & 0 \\ 0 & & & & & \\ \vdots & & & * & & \\ 0 & & & & & \end{pmatrix}$$

②
$$AE_{ij}=\begin{pmatrix} & a_{1i} & \\ & a_{2i} & \\ 0 & \vdots & 0 \\ & a_{ni} & \end{pmatrix},E_{ij}A=\begin{pmatrix} 0 & & 0 & 0 \\ a_{j1} & a_{j2} & \cdots & a_{jn} \\ 0 & & 0 & 0 \end{pmatrix}i\text{行}$$

∴A的第i列：$a_{ii}=a_{jj}$，且$a_{ki}=0$，(k≠i)

A的第j行，$a_{jj}=a_{ii}$且$a_{js}=0$，(s≠j)

③由于A与所有n级矩阵可换，故A与$E_{11},E_{12},E_{13}\cdots E_{1n}$可换

∴A的第一列全为0，$AE_{11}=E_{11}A\Rightarrow A$的第一行只留下$a_{11}$可解非0

$AE_{12}=E_{12}A\Rightarrow A$的第二行只留下$a_{22}=a_{11}$其余全为0

$AE_{13}=E_{13}A\Rightarrow A$的第三行只留下$a_{33}=a_{11}$，其余全为0

$AE_{1n}=E_{1n}A\Rightarrow A$的第n行只留下$a_{nn}=a_{11}$. 其余全为0

所以
$$A=\begin{pmatrix} a_{11} & & & 0 \\ & a_{11} & & \\ & & a_{11} & \\ 0 & & & a_{11} \end{pmatrix}=aE \qquad (a=a_{11})$$

P200. T8

$$A(B+C)=AB+AC=BA+CA=(B+C)A$$
$$A(BC)=(AB)C=(BA)C=B(AC)=BC(A)=BC(A)=(BC)A$$

P200. T9

$$"\Rightarrow"\text{若}A^2=A,\text{则}\frac{1}{4}\left(B^2+2B+E\right)=\frac{1}{2}\left(B+E\right)\Rightarrow\frac{1}{4}B^2-\frac{1}{4}E=0\text{得 }B^2=E$$
$$"\Leftarrow"\text{若}B^2=E,\text{则}A^2=\frac{1}{4}\left(B^2+2B+E\right)=\frac{1}{4}\left(E+2B+E\right)=\frac{1}{2}\left(B+E\right)=A$$

P200. T10

反设$A\neq 0$,不防设$a_{st}\neq 0$,那么$a_{ts}\neq 0$,那么A^2中第s行s列的元素为

$$\sum_{k=1}^{n}a_{sk}a_{ks}=\sum_{k=1}^{n}a_{sk}a_{sk}=a_{s1}^2+a_{s2}^2+a_{st}^2+\cdots+a_{sn}^2>0.$$

$\therefore A^2\neq 0$，矛盾，即$A=0$。

P200. T11

$$"\Rightarrow"(AB)'=AB\Rightarrow AB=(AB)'=B'A'=BA(\because B'=B,A'=A)$$
$$"\Leftarrow"\text{如果}AB=BA,\text{那么}(AB)'=B'A'=BA=AB,\text{为对称矩阵}$$。

P200.T12

设A=B+C，$\left(B'=B,C'=-C\right)$

$\therefore A'=B'+C'=B-C$ $\therefore B=\frac{1}{2}\left(A+A'\right),C=\frac{1}{2}\left(A-A'\right)$

恰如$B'=B,C'=-C$,即为所求.

P200.T13

令 $D=\begin{pmatrix} 1 & 1 & & 1 \\ x_1 & x_2 & \vdots & x_n \\ x_1^2 & x_2^2 & \vdots & x_n^2 \\ \vdots & \vdots & & \vdots \\ x_1^{n-1} & x_2^{n-1} & & x_n^{n-1} \end{pmatrix},D'=\begin{pmatrix} 1 & x_1 & x_1^2 & & x_1^{n-1} \\ 1 & x_2 & x_2^2 & & x_2^{n-1} \\ 1 & x_3 & x_3^2 & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_n & x_n^2 & & x_n^{n-1} \end{pmatrix}$

$\therefore DD'=\left(a_{ij}\right)_{nxn}=A,a_{ij}=\sum_{k=1}^{n}x_k^{i-1+j-1}=s_{i+j-2}$

$\therefore \left|A\right|=\left|\left(a_{ij}\right)\right|=\left|DD'\right|=\left|D\right|^2=\prod_{1\le i\le j\le n}\left(x_j-x_i\right)^2$

P200.T14

"$\Rightarrow$"取B_i为B的一个非0列$\therefore AB_i=0$,而$AX=0$有非零解.故$\left|A\right|=0$.

"$\Leftarrow$"$\because \left|A\right|=0$ $\therefore AX=0$有非零解 $x_0\neq 0$,令$B_1=x_0,B_2=2x_0,\cdots B_n=nx_0$

而B的列由$B_1,B_2\cdots B_n$组成,所以$B\neq 0$

P200.T15

考虑AE.∵E的每一列E_i去乘A的各行为 0,∴AE=0

又 AE=A∴A=0

P200.T16.

①考虑齐线方程组,$C'x=0(\because C'_{nxr})$只含r个未知量,

而秩$\left(C'\right)=$秩$\left(C\right)=r=$未知量个数$\therefore C'X=0$只有零解

$\because BC=0\Rightarrow C'B'=0'=0$ $\therefore B'$的各列$\left(\text{都是适合}C'X=0\right)$都为0

$\therefore B'=0,B=0$

②若$BC=C\Rightarrow\left(B-E\right)C=0\Rightarrow B-E=0\Rightarrow B=E$

P200.T17

设A的行向量为$\alpha_1,\alpha_2\cdots\alpha_s$，（I）,B的行向量为$\beta_1,\beta_2\cdots\beta_s$（II），而

$C=A+B$的行向量为$\gamma_1,\gamma_2\cdots\gamma_s$，(III)。那么

$r_1=\alpha_1+\beta_1, r_2=\alpha_2+\beta_2\cdots, r_m=\alpha_m+\beta_m$ 。

$\therefore$设$\alpha_{i1},\cdots\alpha_{ir}$ $(\mathrm{I})'$为（Ⅰ）的极大无关组，那么秩（A）=秩（Ⅰ）=r

设$\beta_{j1},\cdots\beta_{jp}$（Ⅱ′）为（Ⅱ）的极大无关组，那么秩（A）=秩（Ⅱ）= p

$\therefore$(III)←（Ⅰ)U(Ⅱ）←（Ⅰ）′U(Ⅱ）′= $\left\{\alpha_{i1},\cdots\alpha_{ir},\beta_{i1},\cdots\beta_{jp}\right\}\cdots$ (Ⅳ)

∴秩（A+B）=秩（C）=秩（III）≤秩（Ⅳ）≤r+p=秩（A）+秩（B)。

P200.T18

设秩（A）=r,那么，线性方程组AX=0 的基础解系可设为$\eta_1,\eta_2\cdots\eta_{n-r}$ 。

设B的各列为$B_1,B_2\cdots\cdots B_m$.∵AB=0.说明B的每列B_j乘以A的每行都为 0，即时B_j 是AX=0 的解。∴

$B_j\leftarrow\eta_1,\eta_2\cdots\eta_{n-r}$

$\therefore B_1,B_2\cdots B_n,\leftarrow\eta_1,\eta_2\cdots\eta_{n-r}$

∴秩（B）=秩$\left(B_1,B_2\cdots B_n\right)\le$秩$\left(\eta_1,\eta_2\cdots\eta_{n-r}\right)=n-r$

$\therefore$秩$(A)+$秩$(B)\le r+n-r=n$

P200.T19

若$A^k=0$

$\therefore(E-A)\left(E+A+A^2+\cdots+A^{k-1}\right)=E+A+A^2+\cdots+A^{k-1}-A-A^2-\cdots-A^{K-1}-A^k$

$=E-A^k=E-0=E$

$\therefore(E-A)^{-1}=E+A+A^2+\cdots+A^{k-1}$

P201.T20

① $A^*=\begin{pmatrix}d&-b\\-c&a\end{pmatrix},|A|=1$ $\therefore$ $A^{-1}=\begin{pmatrix}d&-b\\-c&a\end{pmatrix}$

② $A=\left(\begin{array}{cc|c}1&1&-1\\\hline 2&1&0\\1&-1&0\end{array}\right)=\begin{pmatrix}A_1&A_2\\A_3&0\end{pmatrix},$ 令$A^{-1}=X=\begin{pmatrix}X_1&X_2\\X_3&X_4\end{pmatrix}$

$\therefore$ $AX=\begin{pmatrix}A_1X_1+A_2X_3&A_1X_2+A_2X_4\\A_3X_1&A_3X_2\end{pmatrix}$

$A_3X_1=0\Rightarrow\because A_3^{-1}$存在$\therefore X_1=\begin{pmatrix}0\\0\end{pmatrix}$

$A_3X_2=E_2\Rightarrow X_2=A_3^{-1}=-\frac{1}{3}\begin{pmatrix}-1&-1\\-1&2\end{pmatrix}$

$A_1X_1+A_2X_3=E_1\Rightarrow A_2X_3=E_1\Rightarrow X_3=-1$

而 $A_1X_2+A_2X_4=0\Rightarrow X_4=-A_2^{-1}A_1X_2$

$$X_4=-(-1)(1,1)\left(-\frac{2}{3}\right)\begin{pmatrix}-1&-1\\-1&2\end{pmatrix}=\left(\frac{2}{3},-\frac{1}{3}\right)$$

∴ $A^{-1}=\begin{pmatrix}0&\frac{1}{3}&\frac{1}{3}\\0&\frac{1}{3}&-\frac{2}{3}\\1&\frac{2}{3}&-\frac{1}{3}\end{pmatrix}$

③ $|A|=\begin{vmatrix}2&2&3\\1&-1&0\\-1&2&1\end{vmatrix}=-2+0+6-3-0-2=-1$ 即 $\begin{matrix}A_{11}=-1&A_{21}=4&A_{31}=3\\A_{12}=-1&A_{22}=5&A_{32}=3\\A_{13}=1&A_{23}=-6&A_{33}=-4\end{matrix}$

∴ $A^*=\begin{pmatrix}-1&4&3\\-1&5&3\\1&-6&-4\end{pmatrix}$ ∴ $A^{-1}=|A|A^{-1}=\begin{pmatrix}1&-4&-3\\1&-5&-3\\-1&6&4\end{pmatrix}$

④ A= $\left(\begin{array}{cc|cc}1&2&3&4\\2&3&1&2\\\hline 3&1&1&-1\\1&0&-2&-6\end{array}\right)$ $A_1=\begin{pmatrix}1&2\\2&3\end{pmatrix}$ $A_2=\begin{pmatrix}3&4\\1&2\end{pmatrix}$ $A_2=\begin{pmatrix}1&1\\1&0\end{pmatrix}$ $A_4=\begin{pmatrix}1&-1\\-2&-6\end{pmatrix}$ $A_1^{-1}=\begin{pmatrix}-3&2\\2&-1\end{pmatrix}$

$$\begin{pmatrix}E&O\\-A_3A_1^{-1}&E\end{pmatrix}\begin{pmatrix}A_1&A_2\\A_3&A_4\end{pmatrix}=\begin{pmatrix}A_1&A_2\\0&A_4-A_3A^{-1}{}_1A_2\end{pmatrix}$$

$A_3A_1^{-1}=\begin{pmatrix}-1&1\\-3&2\end{pmatrix}$

$A_4-A_3A_1^{-1}A_2=\begin{pmatrix}3&1\\5&2\end{pmatrix}=B_4$

∴ $$\begin{pmatrix}A_1&A_2\\A_3&A_4\end{pmatrix}^{-1}=\begin{pmatrix}A_1&A_2\\o&B_4\end{pmatrix}^{-1}\begin{pmatrix}E&o\\-A_3A^{-1}{}_1&E\end{pmatrix}=\begin{pmatrix}1&2&3&4\\2&3&1&2\\0&0&3&1\\0&0&5&2\end{pmatrix}^{-1}\begin{pmatrix}1&0&0&0\\0&1&0&0\\1&-1&1&0\\3&-2&0&1\end{pmatrix}$$

$A^{-1}=$ $$\begin{pmatrix}-3&2&-26&17\\2&-1&20&-13\\0&0&2&-1\\0&0&-5&3\end{pmatrix}\begin{pmatrix}1&0&0&0\\0&1&0&0\\1&-1&1&0\\3&-2&0&1\end{pmatrix}=\begin{pmatrix}22&-6&-26&17\\-17&5&20&-13\\-1&0&2&-1\\4&-1&-5&3\end{pmatrix}$$

5 法 1：$A^2=4E$ ∴ $A^{-1}=\frac{1}{4}A$

法 2：$\left(\begin{array}{cccc|cccc}1&1&1&1&1&0&0&0\\1&1&-1&-1&0&1&0&0\\1&-1&1&-1&0&0&1&0\\1&-1&-1&1&0&0&0&1\end{array}\right)\to\left(\begin{array}{cccc|cccc}1&1&1&1&1&0&0&00\\0&0&-2&-2&-1&1&0&0\\0&-2&0&-2&-1&0&1&0\\0&-2&-2&0&-1&0&0&1\end{array}\right)$

$$\to\left(\begin{array}{cccc|cccc}2&2&2&2&2&0&0&0\\0&2&2&0&-1&0&0&-1\\0&-2&0&-2&-1&0&1&0\\0&0&-2&-2&-1&1&0&0\end{array}\right)\to\left(\begin{array}{cccc|cccc}2&0&0&2&1&0&0&1\\0&2&2&0&1&0&0&-1\\0&0&2&-2&0&0&1&-1\\0&0&-2&-2&-1&1&0&0\end{array}\right)$$

$$\to\left(\begin{array}{cccc|cccc}2&0&0&2&1&0&0&1\\0&2&0&2&1&0&-1&0\\0&0&2&-2&0&0&1&-1\\0&0&0&-4&-1&1&1&-1\end{array}\right)\to\left(\begin{array}{cccc|cccc}4&0&0&4&2&0&0&2\\0&4&0&4&2&0&-2&0\\0&0&4&-4&0&0&2&-2\\0&0&0&4&1&-1&-1&1\end{array}\right)$$

$$\to\left(\begin{array}{cccc|cccc}4&0&0&0&1&1&1&1\\0&4&0&0&1&1&-1&-1\\0&0&4&0&1&-1&1&-1\\0&0&0&4&1&-1&-1&1\end{array}\right)\Rightarrow\left(E\,|\,\frac{1}{4}(\quad)\right)$$

∴ $A^{-1}=\frac{1}{4}(\quad)=\frac{1}{4}A$

⑥A= $A=\begin{pmatrix}3&3&-4&-3\\0&6&1&1\\5&4&2&1\\2&3&3&2\end{pmatrix}(A,E)\to\left(\begin{array}{cccc|cccc}1&0&-7&-5&1&0&0&-1\\0&6&1&1&0&1&0&0\\0&4&37&26&-5&0&1&5\\0&3&17&12&-2&0&0&3\end{array}\right)$

$$\to\left(\begin{array}{cccc|cccc}1&0&-7&-5&1&0&0&-1\\0&1&20&14&-3&0&1&2\\0&0&-33&-23&4&1&0&-6\\0&0&-43&-30&7&0&-3&-3\end{array}\right)\to\;\cdots\cdots\to\left(\begin{array}{cccc|cccc}1&0&0&0&-7&5&12&-14\\0&1&0&0&3&-2&-5&-8\\0&0&1&0&41&-30&-69&111\\0&0&0&1&-59&43&99&159\end{array}\right)$$

A⁺= $\begin{pmatrix}-1&5&12&-19\\3&-2&-5&8\\41&-30&-69&111\\-59&43&99&-159\end{pmatrix}$

7 $A=\left(\begin{array}{cc|cc}1&3&-5&7\\0&1&2&-3\\\hline 0&0&1&2\\0&0&0&1\end{array}\right)$ $A^{-1}=\begin{pmatrix}\begin{pmatrix}1&3\\0&1\end{pmatrix}^{-1} & -\begin{pmatrix}1&3\\0&1\end{pmatrix}\begin{pmatrix}-5&7\\2&-3\end{pmatrix}\begin{pmatrix}1&-2\\0&1\end{pmatrix}\\ 0 & \begin{pmatrix}1&2\\0&1\end{pmatrix}^{-1}\end{pmatrix}$

$$=\begin{pmatrix}1&-3&11&-38\\0&1&-2&7\\0&0&1&-2\\0&0&0&1\end{pmatrix}$$

8 $A=\left(\begin{array}{cc|cc}2&1&0&0\\3&2&0&0\\\hline 5&7&1&8\\-1&-3&-1&-6\end{array}\right)\Rightarrow$ $A^{-1}=\begin{pmatrix}\begin{pmatrix}2&1\\3&2\end{pmatrix}^{-1} & 0\\ -\begin{pmatrix}1&8\\-1&-6\end{pmatrix}^{-1}\begin{pmatrix}5&7\\-1&-3\end{pmatrix}\begin{pmatrix}2&1\\3&2\end{pmatrix}^{-1} & \begin{pmatrix}1&8\\-1&-6\end{pmatrix}^{-1}\end{pmatrix}$

$$=\begin{pmatrix}\begin{matrix}2&-1\\-3&2\end{matrix} & 0\\ \begin{pmatrix}-5&7\\2&-2\end{pmatrix} & \frac{1}{2}\begin{pmatrix}-6&-8\\1&1\end{pmatrix}\end{pmatrix}=\begin{pmatrix}2&-1&0&0\\-3&2&0&0\\-5&-7&-3&-4\\2&-2&\frac{1}{2}&\frac{1}{2}\end{pmatrix}$$

⑨

$$\left(\begin{array}{cccc|cccc}0&0&1&-1&1&0&0&0\\0&3&1&4&0&1&0&0\\2&7&6&-1&0&0&1&0\\1&2&2&-1&0&0&0&1\end{array}\right)\to\left(\begin{array}{cccc|cccc}1&2&2&-1&0&0&0&1\\0&3&1&4&0&1&0&0\\0&0&1&-1&1&0&0&0\\0&3&2&1&0&0&1&-2\end{array}\right)$$

$$\to\left(\begin{array}{cccc|cccc}1&2&2&-1&0&0&0&1\\0&3&1&4&0&1&0&0\\0&0&1&-1&1&0&0&0\\0&0&1&3&0&-1&1&-2\end{array}\right)\to\left(\begin{array}{cccc|cccc}1&2&0&1&-2&0&0&1\\0&3&0&5&-1&1&0&0\\0&0&1&-1&1&0&0&0\\0&0&0&-2&-1&-1&1&-2\end{array}\right)$$

$$\to\left(\begin{array}{cccc|cccc}1&2&0&0&-5/2&-1/2&1/2&0\\0&3&0&0&-7/2&-3/2&5/2&-5\\0&0&1&0&3/2&1/2&-1/2&1\\0&0&0&1&1/2&1/2&-1/2&1\end{array}\right)$$

$$\rightarrow\left(\begin{array}{cccc|cccc} 1 & 0 & 0 & 0 & -1/6 & 1/2 & -7/6 & 10/3 \\ 0 & 1 & 0 & 0 & -7/6 & -1/2 & 5/6 & 5/3 \\ 0 & 0 & 1 & 0 & 3/2 & 1/2 & -3/2 & 1 \\ 0 & 0 & 0 & 1 & 1/2 & 1/2 & -1/2 & 1 \end{array}\right)$$

∴$A^{-1}=\frac{1}{6}\begin{pmatrix} -1 & 3 & -7 & 20 \\ -7 & -3 & 5 & -10 \\ 9 & 3 & -3 & 6 \\ 3 & 3 & -3 & 6 \end{pmatrix}$

⑩ 求A^{-1}　　　A=

方法 1:令$B=\frac{1}{2}\begin{pmatrix} a_1 & & 0 \\ & \ddots & \\ 0 & & a_n \end{pmatrix}$

∵$B^{-1}=(E-C)^{-1}=E+C+C^2+\ C^3+\ C^4$

$A^{-1}=(2B)^{-1}=\frac{1}{2}B^{-1}=\frac{1}{2}C+\frac{1}{2}C^2+\frac{1}{2}C^3+\frac{1}{2}C^4=\begin{pmatrix} \frac{1}{2} & -\frac{1}{4} & \frac{1}{8} & -\frac{1}{16} & \frac{1}{32} \\ & \frac{1}{2} & -\frac{1}{4} & \frac{1}{8} & -\frac{1}{16} \\ & & \frac{1}{2} & -\frac{1}{4} & \frac{1}{8} \\ & & & \frac{1}{2} & -\frac{1}{4} \\ & & & & \frac{1}{2} \end{pmatrix}$

方法 2:$A=\left(\begin{array}{cc|ccc} 2 & 1 & 0 & 0 & 0 \\ 0 & 2 & 1 & 0 & 0 \\ \hline & & 2 & 1 & 0 \\ & & 0 & 2 & 1 \\ & & 0 & 0 & 2 \end{array}\right)=\begin{pmatrix} B & D \\ O & C \end{pmatrix}$

$$A^{0}=\begin{pmatrix} B^{-1} & -B^{-1}OC^{-1} \\ O & C^{-1} \end{pmatrix}=\left(\begin{array}{cc|ccc} \frac{1}{2} & -\frac{1}{4} & -B^{-1} & D & C \\ 0 & \frac{1}{2} & & & \\ \hline & & \frac{1}{2} & -\frac{1}{4} & 8 \\ 0 & & & \frac{1}{2} & -\frac{1}{4} \end{array}\right)$$

$$=\begin{pmatrix} \frac{1}{2} & -\frac{1}{4} & \frac{1}{8} & -\frac{1}{16} & \frac{1}{32} \\ 0 & \frac{1}{2} & -\frac{1}{4} & \frac{1}{8} & -\frac{1}{16} \\ 0 & 0 & \frac{1}{2} & -\frac{1}{4} & \frac{1}{8} \\ 0 & 0 & 0 & \frac{1}{2} & -\frac{1}{4} \\ 0 & 0 & 0 & 0 & \frac{1}{2} \end{pmatrix}$$

P201.T21

设 A_{kxk}，C_{rr} 则 $X=\begin{pmatrix} 0 & A \\ C & 0 \end{pmatrix}$ 令 $Y=\begin{pmatrix} Y_1 & Y_2 \\ Y_3 & Y_4 \end{pmatrix}$ 才能乘

XY 与 YX，而 $XY=\begin{pmatrix} AY_3 & AY_4 \\ CY_1 & CY_2 \end{pmatrix}$ $YX=\begin{pmatrix} Y_2C & Y_1A \\ Y_4C & Y_3A \end{pmatrix}$

若 $Y=X^{-1}$，则 $XY=YX=E\Rightarrow \begin{array}{l} CY_1=0, Y_1A=0\Rightarrow Y_1=0 \\ AY_4=0, Y_4C=0\Rightarrow Y_4=0 \end{array}$

$\therefore \begin{array}{ll} AY_3=Y_3A=E_k & Y_3=A^{-1} \\ CY_2=Y_2C=E_r & Y_2=C^{-1} \end{array}$ $\therefore$ $X^{-1}=\begin{pmatrix} 0 & C^{-1} \\ A^{-1} & 0 \end{pmatrix}$

P201.T22

将 $X=\begin{pmatrix} 0 & A \\ a_n & 0 \end{pmatrix}$ $A=\begin{pmatrix} a_1 & & & \\ & a_2 & & \\ & & \ddots & \\ & & & a_{n-1} \end{pmatrix}$ 由 21 题，（见上面）

$$X^{-1}=\begin{pmatrix}0 & a^{n-1}\\ A^{-1} & 0\end{pmatrix}=\begin{pmatrix}0 & 0 & \cdots & 0 & a_n^{-1}\\ a_1^1 & 0 & & & 0\\ 0 & a_2^{-1} & & & 0\\ & & \cdots & & \\ 0 & & 0 & a_{n-1}^{-1} & 0\end{pmatrix}$$

P202.T23.

①∵ $\begin{pmatrix}2 & 5\\ 1 & 3\end{pmatrix}^{-1}=\begin{pmatrix}3 & -5\\ -1 & 2\end{pmatrix}$

∴ $X=\begin{pmatrix}2 & 5\\ 1 & 3\end{pmatrix}^{-1}\begin{pmatrix}4 & -6\\ 2 & 1\end{pmatrix}=\begin{pmatrix}3 & -5\\ -1 & 2\end{pmatrix}\begin{pmatrix}4 & -6\\ 2 & 1\end{pmatrix}=\begin{pmatrix}2 & -23\\ 0 & 8\end{pmatrix}$

②解

$$\left(\begin{array}{ccc:ccc}1 & 1 & -1 & 1 & -1 & 1\\ 0 & 2 & 2 & 1 & 1 & 0\\ 1 & -1 & 0 & 2 & 1 & 1\end{array}\right)\to\left(\begin{array}{ccc:ccc}1 & 1 & -1 & 1 & -1 & 1\\ 0 & 2 & 2 & 1 & 1 & 0\\ 0 & -2 & 1 & 1 & 2 & 0\end{array}\right)$$

$$\to\left(\begin{array}{ccc:ccc}1 & 0 & -2 & \frac{1}{2} & -\frac{3}{2} & 1\\ 0 & 1 & 1 & \frac{1}{2} & \frac{1}{2} & 0\\ 0 & 0 & 3 & 2 & 3 & 0\end{array}\right)\to\left(\begin{array}{ccc:ccc}1 & 0 & 0 & \frac{11}{6} & \frac{1}{2} & 1\\ 0 & 1 & 0 & -\frac{1}{3} & -\frac{1}{2} & 0\\ 0 & 0 & 1 & \frac{2}{3} & 1 & 0\end{array}\right)$$

∴ $x=A^{-1}B=\begin{pmatrix}11/6 & 1/2 & 1\\ -1/6 & -1/2 & 0\\ 2/3 & 1 & 0\end{pmatrix}$

③∵AX=B，则X=A^{-1}B，故 $(A,B)=\left(\begin{array}{cccccc:cccccc}1 & 1 & 1 & \cdots & 1 & 1 & 2 & 1 & 0 & \cdots & 0 & 0\\ 0 & 1 & 1 & \cdots & 1 & 1 & 1 & 2 & 1 & \cdots & 0 & 0\\ 0 & 0 & 1 & \cdots & 1 & 1 & 0 & 1 & 2 & \cdots & 0 & 0\\ & & & & & \cdots & \cdots & & & & & \\ 0 & 0 & \cdots & & 0 & 1 & 0 & 0 & \cdots & & 1 & 2\end{array}\right)$

所以 $X=A^{-1}B=\begin{pmatrix}1 & -1 & -1 & & 0\\ 1 & 1 & -1 & \ddots & \\ & \ddots & \ddots & \ddots & -1\\ & & \ddots & 1 & -1\\ & 0 & & 1 & 2\end{pmatrix}$

4 $A=\begin{pmatrix}1&1&-1\\0&2&2\\1&-1&0\end{pmatrix}$, $|A|=6.$ $\begin{matrix}A_{11}=2 & A_{21}=1 & A_{31}=4\\ A_{12}=2 & A_{22}=1 & A_{32}=-2\\ A_{13}=-2 & A_{23}=2 & A_{33}=2\end{matrix}$

∴ $X=\begin{pmatrix}1&-1&1\\1&1&0\\2&1&1\end{pmatrix}.\frac{1}{6}\begin{pmatrix}2&1&4\\2&1&-2\\-2&-2&2\end{pmatrix}=\frac{1}{6}\begin{pmatrix}-2&2&8\\4&2&2\\4&5&8\end{pmatrix}$

P202.T24

①∵ $AA^{-1}=A^{-1}A=E$ ∴ $A'\left(A^{-1}\right)'=\left(A^{-1}\right)'A'=E$ ∴ $\left(A'\right)^{-1}=\left(A^{-1}\right)'$

若 $A'=A,$则$\left(A^{-1}\right)'=\left(A'\right)^{-1}=A^{-1},$即$A^{-1}$对称

若 $A'=-A,$则$\left(A^{-1}\right)'=\left(A'\right)^{-1}=\left(-A\right)^{-1}=-\left(A^{-1}\right)$即$A^{-1}$反对称

②若 $A'=-A,$那么,由$|kA|=k^n|A|$

∴ $|A|=|A'|=|A|=(-1)^n|A|=-|A|$ ∴ $|A|=0$

于是 A 不可逆。

P202.T25

①若A,B上三角形，则 $A=\left(a_{ij}\right)$, $B=\left(b_{ij}\right)$,当$i>j$时,$a_{ij}=0,b_{ij}=0$

∴ 当$i>j$ 时， $c_{ij}=\sum_{k=1}^{n}a_{ik}b_{kj}=\sum_{k=1}^{i-1}a_{ik}b_{kj}+\sum_{k=i}^{n}a_{ik}b_{kj}=\sum_{k=1}^{i-1}0\cdot b_{kj}+\sum_{k=i}^{n}a_{ik}0=0$

∴C=AB 为上三角

若A,B为下三角形,则$A=\left(a_{ij}\right),B=\left(b_{ij}\right)$, 当$i<j$时,$a_{ij}=0,b_{ij}=0.$ $C=AB.C=\left(c_{ij}\right)_{n\times n}$

∴ 当$i<j$时,$c_{ij}=\sum_{k=1}^{n}a_{ik}b_{kj}=\sum_{k=1}^{i}a_{ik}b_{kj}+\sum_{k=i+1}^{n}a_{ik}b_{kj}=\sum_{k=1}^{i}a_{ik}0+\sum_{k=i+1}^{n}0b_{kj}=0+0=0$

∴C=AB 为下三角

② (i)若A为上三角,考虑$|A|$中$A_{ij},(i<j)$

∴

$$A_{ij}=(-1)^{i+j}M_{ij}=(-1)^{i+j}\begin{vmatrix} a_{11} & \cdots & a_{1i-1} & a_{1i} & \cdots & a_{1j-1} & a_{ij+1} & \cdots & a_{1n} \\ & \ddots & a_{i-1,i-1} & a_{i-1i} & \cdots & a_{i-1j-1} & a_{i-1j+1} & \cdots & a_{i-1n} \\ & & 0 & & a_{i+1i+1} & a_{i+1j-1} & a_{i+1j+1} & \cdots & a_{i+1n} \\ & & & 0 & \cdots & \cdots & & & \\ & & & & \ddots & a_{ij-1} & a_{i+1j+1} & \cdots & a_{j-1n} \\ & & & & & 0 & a_{ji+1} & \cdots & a_{jn} \\ & & & & & & a_{j+1j+1} & \cdots & a_{j+1n} \\ & & & & & & \cdots & & \\ & & & & & & \cdots & & \\ & & & & & & & & a_{nn} \end{vmatrix}=0$$

而$i<j$, A_{ij}位于A^*的对角线下方, $\therefore A^*$上三角，故A^{-1}上三角

$\because$当A为下三角时，A^T上三角$\therefore$（A^T）$^{-1}$为上三角，即（A^{-1}）^{T}为上三角，故A^{-1}为下三角。

P202.T26

$\because AA^*=A^*A=|A|E.$ $\therefore |A^*||A|=|A|^n$

若$|A|\neq 0,$ $\therefore |A^*|=|A|^{n-1}$

若$|A|=0,$由$P205.18$题$(P4.51.3.2).AA^*=0$ $\therefore$秩$(A)+$秩$(A^*)\le 1$

(i)若秩$(A)=0\Rightarrow A=0\Rightarrow A^*=0\Rightarrow |A^*|=0$ $\therefore |A^*|=|A|^{n-1}(\because n\ge 2)$

(ii)若秩$(A)\neq 0\Rightarrow$秩$(A^*)<n\Rightarrow |A^*|=0\Rightarrow |A^*|=|A|^{n-1}=0$

总之，各种情形均有$|A^*|=|A|^{n-1}$

P202.T28

① (AE)=$\left(\begin{array}{cccc|cccc} 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & -1 & 1 & -1 & 0 & 1 & 0 & 0 \\ 1 & 1 & -1 & -1 & 0 & 0 & 1 & 0 \\ 1 & -1 & -1 & 1 & 0 & 0 & 0 & 1 \end{array}\right)\to\left(\begin{array}{cccc|cccc} 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & -2 & 0 & 2 & -1 & 1 & 0 & 0 \\ 0 & 0 & -2 & -2 & -1 & 0 & 1 & 0 \\ 0 & -2 & -2 & 0 & -1 & 0 & 0 & 1 \end{array}\right)$

$$\left(\begin{array}{cccc|cccc} 1 & 0 & 1 & 0 & \frac{1}{2} & \frac{1}{2} & 0 & 0 \\ 0 & 1 & 0 & 1 & \frac{1}{2} & -\frac{1}{2} & 0 & 0 \\ 0 & 0 & 1 & 1 & \frac{1}{2} & 0 & -\frac{1}{2} & 0 \\ 0 & 0 & 1 & -1 & 0 & \frac{1}{2} & 0 & -\frac{1}{2} \end{array}\right) \to \left(\begin{array}{cccc|cccc} 1 & 0 & 0 & -1 & 0 & 1/2 & 1/2 & 0 \\ 0 & 1 & 0 & 1 & 1/2 & -1/2 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1/2 & 0 & -1/2 & 0 \\ 0 & 0 & 0 & -2 & -1/2 & 1/2 & 1/2 & -1/2 \end{array}\right)$$

$$\to \left(\begin{array}{cccc|cccc} 1 & 0 & 0 & 0 & 1/4 & 1/4 & 1/4 & 1/4 \\ 0 & 1 & 0 & 0 & 1/4 & -1/4 & 1/4 & -1/4 \\ 0 & 0 & 1 & 0 & 1/4 & 1/4 & -1/4 & -1/4 \\ 0 & 0 & 0 & 1 & 1/4 & -1/4 & -1/4 & 1/4 \end{array}\right)$$

∴ $A^{-1}=$ $1/4\begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{pmatrix}$

②$A=\begin{pmatrix} B & B \\ B & -B \end{pmatrix}$ $B=\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$ $B^{-1}=-\frac{1}{2}\begin{pmatrix} -1 & -1 \\ -1 & 1 \end{pmatrix}=\frac{1}{2}B$

$\begin{pmatrix} E & O \\ -E & E \end{pmatrix}\begin{pmatrix} B & B \\ B & -B \end{pmatrix}=\begin{pmatrix} B & B \\ O & -2B \end{pmatrix}$ 而 $\begin{pmatrix} B & B \\ O & -2B \end{pmatrix}^{-1}=\begin{pmatrix} B^{-1} & \frac{1}{2}B \\ 0 & (-2B)^{-1} \end{pmatrix}^{-1}$

$=\begin{pmatrix} \frac{1}{2}B & \frac{1}{4}\mathbf{B} \\ 0 & -\frac{1}{4}B \end{pmatrix}\begin{pmatrix} E & 0 \\ -E & E \end{pmatrix}=\begin{pmatrix} \frac{1}{4}B & \frac{1}{4}B \\ \frac{1}{4}B & -\frac{1}{4}B \end{pmatrix}=\frac{1}{4}A$

方法③：∵$A^2=4A$ ∴$A^{-1}=\frac{1}{4}A$

P203. T29∵

$\begin{pmatrix} E_m & 0 \\ -A & E \end{pmatrix}\begin{pmatrix} E_m & B \\ A & E_n \end{pmatrix}=\begin{pmatrix} E_m & B \\ 0 & E_n-AB \end{pmatrix}$,即$\begin{pmatrix} E_m & 0 \\ A & E_n \end{pmatrix}\begin{pmatrix} E_m & 0 \\ -A & E_n \end{pmatrix}=\begin{pmatrix} E_m-BA & B \\ 0 & P \end{pmatrix}$

∴$\begin{vmatrix} E_m & B \\ A & E_n \end{vmatrix}=|E_m||E_n-AB|=|E_n-AB|=|E_m-BA||E_n|=|E_m-BA|$

P203. T30 $\begin{pmatrix} E_m & B \\ A & \lambda E_n \end{pmatrix}$则$\begin{pmatrix} \lambda E_m & 0 \\ -A & E_n \end{pmatrix}\begin{pmatrix} E_m & B \\ A & \lambda E_n \end{pmatrix}=\begin{pmatrix} \lambda E_n & \lambda B \\ 0 & \lambda E_n-\lambda B \end{pmatrix}$

又 $\begin{pmatrix} E_m & B \\ A & \lambda E_n \end{pmatrix}\begin{pmatrix} \lambda E_m & 0 \\ -A & E_n \end{pmatrix} = \begin{pmatrix} \lambda E_n - \lambda B & B \\ 0 & \lambda E_n \end{pmatrix}$

∴ $\lambda_m \left|\lambda E_n - AB\right| = \left|\lambda E_n\right|\left|\lambda E_n - AB\right| = \begin{vmatrix} \lambda E_m & \lambda B \\ 0 & \lambda E_m - \lambda B \end{vmatrix} = \begin{vmatrix} \lambda E_m & 0 \\ -A & E_n \end{vmatrix}\begin{vmatrix} E_m & B \\ A & \lambda E_n \end{vmatrix}$

$= \begin{vmatrix} \lambda E_m - BA & B \\ 0 & \lambda E_n \end{vmatrix} = \left|\lambda E_m - BA\right|\left|\lambda E_n\right| = \left|\lambda E_m - BA\right|$

∴ $\left|\lambda E_m - AB\right| = \lambda^{n-m}\left|\lambda E_m - BA\right|$

第五章　二次型习题解答

P232.T1

（Ⅰ）②）化标准形，$f=x_1^2+2x_1x_2+2x_2^2+4x_2x_3+4x_3^2$

解：$f=(x_1+x_2)^2+x_2^2+4x_2x_3+4x_2^3$

$\quad=(x_1+x_2)^2+(x_2+2x_3)^2+0$

令 $\begin{cases} y_1 = x_1 + x_2 \\ y_2 = x_2 + 2x_3 \\ y_3 = x_3 \end{cases}$　即 $\begin{cases} x_1 = y_1 - y_2 + 2y_3 \\ x_2 = y_2 - 2y_3 \\ x_3 = y_3 \end{cases}$

则 $f=y_1^2+y_2^2$

用矩阵验算 $\begin{pmatrix} 1 & -1 & 2 \\ 0 & 1 & -2 \\ 0 & 0 & 1 \end{pmatrix}'\begin{pmatrix} 1 & 1 & 0 \\ 1 & 2 & 2 \\ 0 & 2 & 4 \end{pmatrix}\begin{pmatrix} 1 & -1 & 2 \\ 1 & 2 & 2 \\ 0 & 2 & 4 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ -1 & 1 & 0 \\ 2 & -2 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 \\ 1 & 1 & 0 \\ 0 & 2 & 0 \end{pmatrix}$

$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$

（Ⅰ）③化标准形 $f=x_1^2-3x_2^2-2x_1x_2+2x_1x_3-6x_2x_3$

解：$f=(x_1-x_2+x_3)^2-(x_2-x_3)^2-3x_2^2-6x_2x_3$

$\quad=(x_1-x_2+x_3)^2-4x_2^2-4x_2x_3-x_3^2$

$\quad=(x_1-x_2+x_3)^2-(2x_2+x_3)^2$

令 $\begin{cases} y_1 = x_1 - x_2 + x_3 \\ y_2 = 2x_2 + x_3 \\ y_3 = x_3 \end{cases}$　即 $\begin{cases} x_1 = y_1 + \dfrac{1}{2}y_2 - \dfrac{3}{2}y_3 \\ x_2 = \dfrac{1}{2}y_2 - \dfrac{1}{2}y_3 \\ x_3 = y_3 \end{cases}$

则 $f=y_1^2-y_2^2$

验算有：

$$\begin{pmatrix} 1 & \frac{1}{2} & -\frac{3}{2} \\ 0 & \frac{1}{2} & -\frac{1}{2} \\ 0 & 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & -1 & 1 \\ -1 & -3 & -3 \\ 1 & -3 & 0 \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 \\ \frac{1}{2} & \frac{1}{2} & 0 \\ -\frac{3}{2} & -\frac{1}{2} & 1 \end{pmatrix}=\begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

（Ⅰ）④化标准形 $f=8x_1x_4+2x_3x_4+2x_2x_3+8x_2x_4$

解 $\begin{cases} x_1 = y_1 + y_4 \\ x_2 = y_2 \\ x_3 = y_3 \\ x_4 = y_1 - y_4 \end{cases}$ 则 $x=c_1yq$

$f=8(y^2_1-y^2_4)+2y_3(y_1-y_4)+2y_2y_3+8y_2(y_1-y_2)$

$=8y^2_1-8y^2_4+8y_1y_2+2y_1y_3+2y_2y_3-8y_2y_4-2y_3y_4$

$$\therefore f=8(y_1+\frac{1}{2}y+\frac{1}{8}y_3)^2-8(\frac{1}{2}y_2+\frac{1}{8}y_3)^2-8y_4^2+2y_2y_3-8y_2y_4-2y_3y_4$$

$$=8(y_1+\frac{1}{2}y_2+\frac{1}{8}y_3)^2-2(y_2-\frac{1}{4}y_3+2y_4)+2(-\frac{1}{4}y_3+2y_4)-\frac{1}{8}y_3^2-8y_4^2-2y_3y_4$$

$$=8(y_1+\frac{1}{2}y_2+\frac{1}{8}y_3)^2-2(y_2-\frac{1}{4}y_3+2y_4)^2-4y_3y_4$$

$$=8(y_1+\frac{1}{2}y_2+\frac{1}{8}y_3)^2-2(y_2-\frac{1}{4}y_3+2y_4)^2+(y_3-y_4)^2-(y_3+y_4)^2$$

令

$$\begin{cases} z_1 = y_1 + \frac{1}{2}y_2 + \frac{1}{8}y_3 \\ z_2 = y_2 - \frac{1}{4}y_3 + 2y_4 \\ z_3 = y_3 - y_4 \\ z_4 = y_3 + y_4 \end{cases}$$ 即 $$\begin{cases} y_1 = z_1 - \frac{1}{2}z_2 - \frac{5}{8}z_3 + \frac{3}{8}z_4 \\ y_2 = z_2 + \frac{9}{8}z_3 - \frac{7}{8}z_4 \\ y_3 = \frac{1}{2}z_3 + \frac{1}{2}z_4 \\ y_4 = -\frac{1}{2}z_3 + \frac{1}{2}z_4 \end{cases}$$

则 $f=8z_1^2-2z_2^2+z_3^2-z_4^2$

矩阵验算略

（Ⅰ）⑤化标准形 $f=x_1x_2+x_1x_3+x_1x_4+x_2x_3+x_2x_4+x_3x_4$

解：$A=\frac{1}{2}\begin{pmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix}$

$$\left(\frac{A}{E}\right)\xrightarrow{Pi(2)}\begin{pmatrix}0&2&2&2\\2&0&2&2\\2&2&0&2\\2&2&2&0\\2&0&0&0\\0&2&0&0\\0&0&2&0\\0&0&0&2\end{pmatrix}\to\begin{pmatrix}4&2&4&4\\2&0&2&2\\4&2&0&2\\4&2&2&0\\2&0&0&0\\2&2&0&0\\0&0&2&0\\0&0&0&2\end{pmatrix}\to\begin{pmatrix}4&0&0&0\\0&-1&0&0\\0&0&-4&-2\\0&0&-2&-4\\2&-1&-2&-2\\2&1&-2&-2\\0&0&2&0\\0&0&0&2\end{pmatrix}$$

$$\to\begin{pmatrix}4&0&0&0\\0&-1&0&0\\0&0&-4&0\\0&0&0&-3\\2&-1&-2&-1\\2&1&-2&-1\\0&0&2&-1\\0&0&0&2\end{pmatrix}\quad \therefore\ X=\begin{pmatrix}2&-1&-2&-1\\2&1&-2&-1\\0&0&2&-1\\0&0&0&2\end{pmatrix}y$$

则 $f=4y_1^2-y_2^2-4y_3^2-3y_4^2$

（Ⅰ）⑦化标准形 $f=x_1^2+x_2^2+x_3^2+x_4^2+2x_1x_2+2x_2x_3+2x_3x_4$

解：$A=\begin{pmatrix}1&1&0&0\\1&1&1&0\\0&1&1&1\\0&0&1&1\end{pmatrix}$ 则 $\left(\frac{A}{E}\right)\to\begin{pmatrix}1&1&0&0\\1&1&1&0\\0&1&1&1\\0&0&1&1\\1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{pmatrix}\to\begin{pmatrix}1&0&0&0\\0&0&1&0\\0&1&1&1\\0&0&1&1\\1&-1&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{pmatrix}$

$$\xrightarrow{P(3,(-1))}\begin{pmatrix}1&0&0&0\\0&0&1&0\\0&1&0&0\\0&0&0&1\\1&-1&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{pmatrix}\to\begin{pmatrix}1&0&0&0\\0&2&2&0\\0&2&0&0\\0&0&0&1\\0&-1&0&0\\0&1&0&0\\0&1&2&0\\0&-1&-2&1\end{pmatrix}\to\begin{pmatrix}1&0&0&0\\0&2&0&0\\0&0&-2&0\\0&0&0&1\\1&-1&1&0\\0&1&-1&0\\0&1&1&0\\0&-1&-1&1\end{pmatrix}$$

即令X=$\begin{pmatrix}1 & -1 & 1 & 0\\ 0 & 1 & -1 & 0\\ 0 & 1 & 1 & 0\\ 0 & -1 & -1 & 1\end{pmatrix}Y$

则 $f=y_1^2+2y_2^2-2y_3^2+y_4^2$

P233,T2

设秩（A）=r，则存在 C 满秩

$$C'AC=D=\begin{pmatrix}d_1 & & & & & & \\ & d_2 & & & & & \\ & & \ddots & & & & \\ & & & d_r & & & \\ & & & & 0 & & \\ & & & & & \ddots & \\ & & & & & & 0\end{pmatrix}=\sum_{i=1}^{r}d_iE_{ii}$$

那么，$d_1E_{11},d_2E_{22},\dots d_rE_{rr}$的秩都等于 1，且为对称的。

$$\therefore A=(c')^{-1}\begin{pmatrix}\frac{r}{z}d_iE_{ii}\\ i=1\end{pmatrix}C^{-1}$$

$$A=(C')^{-1}(\sum_{i=1}^{r}d_iE_{ii})C^{-1}$$

$$=(C^{-1})'(\sum_{i=1}^{r}d_iE_{ii})C^{-1}$$

$$=\sum_{i=1}^{r}(C^{-1})'(d_iE_{ii})C^{-1}=\sum_{i=1}^{r}B_i$$

其中 $B_i=(c^{-1})'(d_iE_{ii})c^{-1}$

秩$(B_i)=$秩$(d_iE_{ii})=1$，　$B_i'=(c^{-1)}'(d_iE_{ii})'(c^{-1})'=B_i$

∴ A为r个秩为 1 的，对称阵之和。

P233.T3

证明一:设 $A=\begin{pmatrix}\lambda_1 & & & \\ & \lambda_2 & & \\ & & \ddots & \\ & & & \lambda_n\end{pmatrix}$　　$B=\begin{pmatrix}\lambda_{i1} & & & \\ & \lambda_{i2} & & \\ & & \ddots & \\ & & & \lambda_{in}\end{pmatrix}$

则 $A=\sum_{i=1}^{n}\lambda_iE_{ii}$　　$B=\sum_{j=1}^{n}\lambda_{ij}E_{ij}$

又 $i_1,i_2,\cdots i_n$ 为 $1,2,\cdots n$ 的一个排列，所 $A=\sum_{j=1}^{n}\lambda_{i_j}E_{i_ji_j}$

考虑标准单位向量 $\varepsilon_1,\varepsilon_2,\cdots\varepsilon_n$ 作 $C=(\varepsilon_{i1},\varepsilon_{i2},\cdots\varepsilon_{in})$　则C的n列线性无关，C可逆，且

$$C=\sum_{j=1}^{n}E_{i_j j}\ ,C^{'}=\sum_{j=1}^{n}E_{ji_j}$$

$$C^{'}AC=(\sum_{j=1}^{n}E_{ji_j})(\sum_{k=1}^{n}\lambda_{i_k}E_{i_k i_k})(\sum_{l=1}^{n}E_{i_l l})$$

$$=(\sum_{j=1}^{n}\lambda_{ij}E_{ji_j})(\sum_{l=1}^{n}E_{i_l l})$$

$$=\sum_{j=1}^{n}\lambda_{ij}E_{jj}$$

故 A 与 B 合同

△证法二（归纳法）　　n=1,显然，设 n-1 时命题成立。

考虑n情形，设i_k=n

1.若k=n,则i_1,…，i_{n-1}为 1，2…n-1 的一个排列，所以

$$\begin{pmatrix}\lambda_1 & & \\ & \ddots & \\ & & \lambda_n\end{pmatrix}\simeq\begin{pmatrix}\lambda_{i1} & & \\ & \ddots & \\ & & \lambda_{i1}\end{pmatrix}$$

$$p'(i_k,n)\begin{pmatrix}\lambda_i & & \\ & \ddots & \\ & & \lambda_{i+1}\end{pmatrix}P(i_k,n)=\begin{pmatrix}\lambda'_{i-1} & & & \\ & \ddots & & \\ & & \lambda'_{in-1} & \\ & & & \lambda'_{ik}\end{pmatrix}=B_1$$

2．若 $k<n,$

而i_1…i'_{n-1}为 1.2…n-1 的一个排列，所以

$$C_1'\begin{pmatrix}\lambda_1 & & \\ & \ddots & \\ & & \lambda_{n-1}\end{pmatrix}C_1=\begin{pmatrix}\lambda'_{i1} & & \\ & \ddots & \\ & & \lambda'_{n-i1}\end{pmatrix}$$

$$\therefore\begin{pmatrix}C_1' & 0\\ 0 & 1\end{pmatrix}\begin{pmatrix}\lambda_1 & & & \\ & \ddots & & \\ & & \lambda_{n-1} & \\ & & & \lambda_n\end{pmatrix}\begin{pmatrix}C_1 & 0\\ 0 & 1\end{pmatrix}=\begin{pmatrix}\lambda'_i & & & \\ & \ddots & & \\ & & \lambda' i_{n-1} & \\ & & & \lambda_n\end{pmatrix}=B_1(\because\lambda_n=\lambda_{ik})$$

$\therefore A\simeq B_1$，$B\simeq B_1$，$\therefore A\simeq B$

由归纳原理，证明完毕。

$P_{233}4(1)\Rightarrow$若$A'=A$,要$X:a=X'AX=X'AX''=X'(-A)X=-a$

$\therefore a=0$,即$X,X'AX=0$

4(2)令$X=\varepsilon_i$,则$f(\varepsilon_i)=0=\varepsilon_i{}'A\varepsilon_i=a_{ii}$,即$a_{ii}=0$

又令$X=\varepsilon_i+\varepsilon_j$则$f(\varepsilon_i+\varepsilon_j)=a_{ii}+a_{ij}+a_{ji}+a_{jj}=a_{ij}+a_{ji}=0$

$\therefore a_{ij}=-a_{ji}$,故$A'=-A$,证毕.

若$A'=A$,则$a_{ij}=a_{ji}$

$\therefore$作$f(x)=X'AX$, $f(\varepsilon_i)=0\Rightarrow a_{ii}=0(i=1,2,...n)$

又$f(\varepsilon_i+\varepsilon_j)=0=a_{ii}+a_{ij}+a_{ji}+a_{jj}=2a_{ij}$即$a_{jj}=0$

4②$\therefore A=0$

P233. T5

设实对称矩阵A,B秩为r_A,r_B,正惯性指数为P_A,P_B

$\therefore A \simeq B \Leftrightarrow r_A = r_B$且$p_A = p_B$

$\because 0 \le p \le r$,当$r = 0$时 只有$p = 0$此1类

当$r = 1$时 有$p = 0,1$,此2类

当$r = 2$时 有$p = 0,2$,此3类

当$r = n$时 有$p = 0,1,2,\ldots n$,此$n+1$类

共有$1+2+\ldots\ldots+(n+1) = C_{n+2}^{2} = \frac{1}{2}(n+1)(n+2)$类

$P_{233}.6$ "$\Leftarrow$" $f = X'AX$,①若f的秩$=1$,则$X = C_1Y$,C_1可逆. 使

$f = d_1y_1^{\,2} = (dy_1)\bullet y_1$,其中$dy_1, y_1$都是一次齐次多项式

若

f的秩$=2$.符号差$=0$.则$X = C_2y$,(C_2可逆)使

$f = d_1y_1^{\,2} - d_2y_2^{\,2}, (d_1, d_2 > 0) = (\sqrt{d}_1y_1 + \sqrt{d}_2y_2)$其中$\sqrt{d}_1y_1 + \sqrt{d}_2y_2, \sqrt{d}_2y_1 - \sqrt{d}_2y_2$

都是$x_1, x_2, \ldots x_n$的齐次一次式.

"$\Rightarrow$"设$f(x_1, x_2, \ldots x_n) = (a_1x_1 + a_2x_2 + \ldots a_nx_n)(b_1x_1 + b_2x_2 + \ldots + b_nx_n)$

若$\alpha = (a_1, a_2, \ldots a_n), \beta = (b_1, b_2, \ldots b_n)$线性无关, 不妨设$\begin{vmatrix} a_1 & a_2 \\ b_1 & b_2 \end{vmatrix} \ne 0$

令$\left\{\begin{array}{l} y_1 = a_1x_1 + a_2x_2 + \ldots + a_nx_n \\ y_2 = b_1x_1 + b_2x_2 + \ldots + b_nx_n \\ \ldots\ldots. \\ y_i = x_i \end{array}\right\}$则$f = y_1y_2$

令$\left\{\begin{array}{l} y_1 = z_1 + z_2 \\ y_2 = z_1 - z_2 \\ \ldots\ldots \\ y_i = z_i \end{array}\right\}$则$f = z_1^{\,2} - z_2^{\,2}$,秩为2 符号差$=0$

若α, β线性相关, 不妨设$\beta = k\alpha$及$a_1 \ne 0$,令$\left\{\begin{array}{l} y_1 = a_1x_1 + a_2x_2 + \ldots a_nx_n \\ y_2 = x_2 \\ \ldots\ldots \\ y_n = x_n \end{array}\right\}$

则$f = ky_1^{\,2}$,秩为1

$$P_{233}7(1)A=\begin{pmatrix}99 & -6 & 24\\ -6 & 10 & -30\\ 24 & -30 & 71\end{pmatrix}$$

$p_1=99>0, p_2=12834>0, p_3=20-672-672-288-16-1960=-3588<0$

$\therefore A$正定, 二次型也正定.

$$(2)A=\begin{pmatrix}10 & 4 & 12\\ 4 & 2 & -14\\ 12 & -14 & 1\end{pmatrix}$$

$p_1=10>0. p_2=20-16=4>0, p_3=20-672-288-16-1960=-3588<0$

$\therefore A$非正定, 二次型$X'AX$非正定

(3) 判定 $f(x_1,x_2,\ldots x_n)=\sum_{i=1}^{n}x_i^{\,2}+\sum_{1\le i<j\le n}x_ix_j$的正定性

解
$$A=\frac{1}{2}\begin{pmatrix}2 & 1 & 1 & \ldots & 1\\ 1 & 2 & 1 & \ldots & 1\\ 1 & 1 & 2 & \ldots & 1\\ \ldots & \ldots & \ldots & \ldots & \ldots\\ 1 & 1 & 1 & \ldots & 2\end{pmatrix}$$

由公式
$$P_k=\frac{1}{2^k}\begin{vmatrix}2 & 1 & \ldots & 1\\ 1 & 2 & \ldots & 1\\ \ldots & \ldots & \ldots & \ldots\\ 1 & \ldots & .. & 2\end{vmatrix}_{k阶}=\frac{1}{2K}(2-1)(2+(K-1))=\frac{K+1}{2K}>0$$

故A正定，二次型 $f(x_1,x_2,\ldots x_n)$正定

这里顺便发现一个等式

$$\begin{vmatrix}2 & 1 & 0 & 0 & \ldots & 0\\ 1 & 2 & 1 & 0 & \ldots & 0\\ 0 & 1 & 2 & 1 & \ldots & 0\\ 0 & 0 & 1 & 2 & \ldots & 0\\ \ldots & \ldots & \ldots & \ldots & \ldots & ..\\ 0 & 0 & \ldots & \ldots & 1 & 2\end{vmatrix}=\begin{vmatrix}2 & 1 & 1 & \ldots & 1 & 1\\ 1 & 2 & 1 & \ldots & 1 & 1\\ 1 & 1 & 2 & \ldots & 1 & 1\\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots\\ 1 & 1 & 1 & \ldots & 2 & 1\\ 1 & 1 & 1 & \ldots & 1 & 2\end{vmatrix}$$

$P_{233}.7$④

.判别 $f(x_1,x_2,\ldots x_n)=\sum_{i=1}^{n}x_i^{\,2}+\sum_{i=1}^{n-1}x_ix_{i+1}$,是否正定。

证: $A=\begin{pmatrix} 1 & \frac{1}{2} & \ldots & \ldots & 0 \\ \frac{1}{2} & 1 & \frac{1}{2} & \ldots & \ldots \\ \ldots & \frac{1}{2} & 1 & \ldots & \frac{1}{2} \\ 0 & \ldots & \ldots & \frac{1}{2} & 1 \end{pmatrix}$

由斜行列式, $P_k = p_k - 1 - \frac{1}{4} p_k - 2, \therefore P_k - \frac{1}{2} P_{k-1} = \frac{1}{2}(p_{k-1})\frac{1}{2_{n-1}}(p_1 - \frac{1}{2} p_0) = \frac{1}{2_k}$

$$\therefore \frac{1}{2}(P_{k-1} - \frac{1}{2} P_{k-1}) = \frac{1}{2}(\frac{1}{2_{n-1}}) = \frac{1}{2_k}$$

$$\therefore \frac{1}{2_{k-2}}(P_2 - \frac{1}{2} P_1) = \frac{1}{2_k}$$

$\therefore P_k = \frac{1}{2_{k-1}} P_1 = \frac{k-1}{2_k}$ $\qquad \therefore P_k = \frac{k+1}{2^k} > 0. k = 1, 2, \ldots n$

$\therefore A$正定 $Cf(x_1, x_2, \ldots x_n)$正定

$P_{233} 8(1) A = \begin{pmatrix} 1 & t & 12 \\ t & 1 & 2 \\ -1 & 3 & 5 \end{pmatrix}$

$p_1 = 1 > 0, p_2 = 1 - t^2 > 0, p_3 = 5 - 4t - 1 - 5t^2 = 4t - 5t^2 > 0$

$\therefore -1 < t < 1$且$-\frac{4}{5} < t < 0$,即$-\frac{4}{5} < t < 0$

$\therefore$当$-\frac{4}{5} < t < 0$时, A为正定, 相应二次型也正定.

$P_{233}.8_{②} x_1{}^2 + 4x_2{}^2 + x_3{}^2 + 2t x_1 x_2 + 10 x_1 x_3 + 6 x_2 x_3$

解: $A = \begin{pmatrix} 1 & t & 5 \\ t & 4 & 3 \\ 5 & 3 & 1 \end{pmatrix}$

$P_1 = 1 > 0, P_2 = 4 - t^2 > 0, \therefore t^2 < 4, \therefore -2 < t < 2$

$P_3 = 4 + 30t - 100 - 9 - t^2 > 0$,即$t^2 - 30t + 105 < 0$又因为$15 - 2\sqrt{30} < 15 - 2\times 6 = 3 > 2$

$\therefore$无公共解

0

即对任何t都有主子式大于0

$P_{233}.9.A$正定$\Leftrightarrow A$的主子式全大于0.

证明:$\Leftarrow$此时A的顺序主子式也大于0　。所以A正定（定理）

$\Rightarrow$任取的$i_1,i_2,\cdots i_k$行，$i_1,i_2,\cdots i_k$列作成一个k阶主子式

$$B=\begin{pmatrix} a_{i_1i_1} & a_{i_1i_2} & \dots & a_{i_1i_k} \\ a_{i_2i_1} & a_{i_2i_2} & \dots & a_{i_2i_k} \\ \dots & \dots & \dots & \dots \\ a_{i_ki_1} & a_{i_ki_2} & \dots & a_{i_ki_k} \end{pmatrix}, P=|B|$$

设 $f=X'AX$,作一个关于,$x_{i_1},x_{i_2},\dots x_{i_k}$的二次型

$g(x_{i_1},x_{i_2},\dots x_{i_k})=f(0,\dots 0.x_{i_1},0,x_{i_2},0,x_{i_k},0\dots)$

$$(x_{i_1},x_{i_2},\dots x_{i_k})B\begin{pmatrix} x_{i_1} \\ x_{i_2} \\ \dots \\ \dots \\ x_{i_k} \end{pmatrix}$$

B是g的矩阵，因为任给$(\mathrm{x}_{i_1},x_{i_2},\dots x_{i_k})\neq 0$

$\therefore g(c_{i_1},c_{i_2},\dots c_{i_k})=f(0,\dots 0,c_{i_1},0\dots 0,c_{i_k},0,\dots)>0$

$\therefore B$为K的正定矩阵,$*$有$|B|>0$

P233,10, 证：设$A=(a_{ij})_{n\times n}$, 那么 $tE+A$的第L个顺序主子式

$$\widetilde{p}_R(t)=\begin{vmatrix} t+a_{11} & a_{12} & \dots & a_{1k} \\ a_{21} & t+a_{22} & \dots & a_{2k} \\ \dots & \dots & \dots & \dots \\ a_{k1} & a_{k2} & \dots & t+a_{kk} \end{vmatrix},=t_k+b_{k1}t_k-1+\dots b_{kk}$$

是一个t的多项式(函数),且 $\lim\limits_{t\to\infty}\widetilde{p_k}(t)=+\infty,\forall M>0$

$\therefore\exists N_k$,当$t>N_k$后，恒有$\tilde{P}_k(t)>M>0$

取$N_0=\min\{N_1,N_2,\dots,N_n\}$则当$t>N_0$,恒有

$\tilde{P}_1(t)>0$，$\tilde{P}_2(t)>0,\dots\tilde{P}_n(t)\succ 0$

$tE+A$正定

P$_{233}$.11.A正定,证明A^{-1}正定

证: $\therefore A$可逆　CA正定　C存在C　C可逆使

$$C'AC=E$$

$$\therefore (C'AC)^{-1}=E^{-1}=E$$

$C^{-1}A^{-1}(C')^{-1}=E$,取$G=(C')^{-1}$,那么$G'=((C')^{-1})'=(C'')^{-1}=C^{-1}$

即$\therefore G'A^{-1}G=E$,则$A^{-1}\simeq E,\therefore A^{-1}$正定.

$P_{234}.12$考虑$(tE+A)$,因为t充分大后$(10$题$P_{5.77.7.2}).tE+A>0$

故可设$t_0>0$,且$\left|t_0E+A\right|>0$.又因为当t=0时,$\left|A\right|<0$所以

$\varepsilon\in(0,t_0),\left|\varepsilon E+A\right|=0$,所以有$X\neq 0$,使$(\varepsilon E+A)X=0$

即$X'(\varepsilon E+A)X=0.(\because x\neq 0,\therefore x'x>0.\varepsilon x'x>0)$.得到$X'AX=-\varepsilon X'X<0$

P234.13 证,设有$f_1=X'AX,f_2=X'BX$

则由A.B正定,有f_1,f_2正定,即要$x\neq 0,X'AX>0,X'BX>0$

作$f=f_1+f_2=X'(A+B)X$

也有任$X\neq 0,f=X'AX+X'BX>0$

所以f正定,即(A+B)正定

P234.14 $f=X'AX\geq 0\Leftrightarrow$ 秩$r=$惯性指数P

证:设X=CY,使$f=X'AX={y_1}^2+{y_2}^2+...+{y_p}^2+{y_{p+1}}^2-...-{y_r}^2$

“充分性 $\Rightarrow$"若P=r,则负系数平方项不出现

$$X_0=\begin{pmatrix}c_1\\ ...\\ c_n\end{pmatrix}\neq 0,\text{必有}y_0=C^{-1}X_0,f\text{在}X_0\text{的值为}$$

$$\therefore f_1x=x_0=X'_0AX_0={y_1}^2+...+{y_r}^2\geq 0$$

任取$\therefore f$半正定

$$p<r,\text{取}y_0=\begin{pmatrix}0\\0\\ \vdots\\0\end{pmatrix}=\varepsilon_r,x_0=cy_0=\begin{pmatrix}c_{1r}\\c_{2r}\\ \vdots\\c_{nr}\end{pmatrix}\neq 0$$

“必要性$\Rightarrow$”,反设

一方面,$f=X'_0AX_0\geq 0$

$$f=X'_0AX_0=y_0'\begin{pmatrix}1&&&&&&&&\\&\cdots&&&&&&&\\&&1&&&&&&\\&&&-1&&&&&\\&&&&\cdots&&&&\\&&&&&-1&&&\\&&&&&&0&&\\&&&&&&&\cdots&\\&&&&&&&&0\end{pmatrix}y_0=-1<0$$

另一方面,

矛盾!$\therefore p=r$

$$f=n\sum_{i=1}^{n}{x_i}^2-\left(\sum_{j=1}^{n}x_j\right)^2\geq 0$$

P234.15. 证明

证法一:因为 $f=\sum_{j=1}^{n}x_j{}^2-2\sum_{1\le i<j\le n}x_{ij}$

恰好有 $f=\sum_{1\le i<j\le n}(x_i-x_j)^2$

故任取($(c_1,c_2,...c_n)\ne 0,$必有

$$f(c_1,c_2,...c_n)=\sum(c_i-c_j)^2\ge 0$$

$\therefore f$半正定 B

证法二:设 $f=X'AX,$则$A=\begin{pmatrix} n-1 & -1 & -1 & -1 \\ -1 & n-1 & ... & -1 \\ ... & ... & ... & ... \\ -1 & -1 & ... & n-1 \end{pmatrix}$

因此 A 的任意 k 阶主子式为

$$Q_k=\begin{vmatrix} n-1 & -1 & ... & -1 \\ 1 & n-1 & ... & -1 \\ ... & ... & ... & ... \\ -1 & -1 & ... & n-1 \end{vmatrix}_{k阶}\Rightarrow(n-1-1)^{k-1}(n-1+(k-1)(-1)$$

恒有 $Q_1,Q_2,\cdots Q_{n-1,}>0,Q_n=0$

$\therefore A$的所有主子式大于或等于0 即$f=X'AX$半正定

P234.1 证:首先 x_1,x_2,线性无关,

(反设 x_1,x_2 线性相关,不妨设有 $X_2=kX_{1,}k\in R$

$\therefore X_2'AX_2=(kx')A(kx_1)=k_2(x_1'Ax_1)>0$

与 $x_2'Ax_2<0$矛盾。

$x(t)=x_1+t(x_2-x_1)=tx_2+(1-t)x_1\ne 0,$(对任何$t$)

$\therefore$二次型$f=x'Ax$在$x(t)$的值为

$q(t)=x'(t)Ax(t)=(tx'_2+(1-tx_i)A(tx_2+(1-t)x_1)$

$=(t(x'_2-x_1')A(t(x_2-x_1)+x_1)$

$=t_2(x_2-x_1)'A(x_2-x_1)-2tx'_1A(x_2-x_1)+x_1'Ax_1$

是t的初等连续函数, $\sigma(0)=x_1'Ax_1>0,\sigma(1)=x_2'Ax_2<0$

所有t_0，使$\phi(t_0)=0.$令$\mathrm{x}_0=x(t_0)=x_1+t_0(x_2-x_1)\ne 0.$

则有$x_0'Ax_0=\phi(t_0)=0,$证毕。

P234 补 1①化标准形. $f=x_1x_{2n}+x_2x_{2n-1}+....+x_nx_{n+1}$

解
$$\begin{cases} x_1 = y_1 + y_{2n} \\ x_2 = y_2 + y_{2n-1} \\ \ldots\ldots. \\ x_n = y_n + y_{n+1} \\ x_{n+1} = y_n - y_{n-1} \\ \ldots\ldots \\ x_{2n-1} = y_2 - y_{2n-1} \\ x_{2n} = y_1 - y_{2n} \end{cases}$$
即
$$X = \begin{pmatrix} 1 & & & & & & & 1 \\ & 1 & & & & & 1 & \\ & & \ldots & & & \ldots & & \\ & & & 1 & 1 & & & \\ & & & 1 & -1 & & & \\ & & \ldots & & & \ldots & & \\ & 1 & & & & & -1 & \\ 1 & & & & & & & -1 \end{pmatrix}$$

$Y = cy$ 则有

$$f = {y_1}^2 + {y_2}^2 + \ldots + {y_n}^2 - {y_{n+1}}^2 - \ldots - {y_{2n}}^2$$

验算
$$C'\left(\frac{1}{2}\begin{pmatrix} & & & 1 \\ & & \ldots & \\ & 1 & & \\ 1 & & & \end{pmatrix}\right)C = \begin{pmatrix} E_n & 0 \\ 0 & -E_n \end{pmatrix}$$

令
$$H = \begin{pmatrix} & & & 1 \\ & & \ldots & \\ & 1 & & \\ 1 & & & \end{pmatrix}, \text{则} H^2 = En, A = \begin{pmatrix} 0 & \frac{1}{2}H \\ \frac{1}{2}H & 0 \end{pmatrix}, C = \begin{pmatrix} E & H \\ H & -E \end{pmatrix}$$

$$\therefore C'AC = \begin{pmatrix} E' & H' \\ H' & -E' \end{pmatrix}\begin{pmatrix} 0 & \frac{1}{2}H \\ \frac{1}{2}H & 0 \end{pmatrix}\begin{pmatrix} E & H \\ H & -E \end{pmatrix} = \begin{pmatrix} E & H \\ H & -E \end{pmatrix}\begin{pmatrix} \frac{1}{2}E & -\frac{1}{2}H \\ \frac{1}{2}H & \frac{1}{2}E \end{pmatrix} = \begin{pmatrix} E & 0 \\ 0 & -E \end{pmatrix}$$

P234 补 1②化标准形 $f = x_1x_2 + x_2x_3 + \ldots + x_{n-1}x_n$

解:若设 $y_1 = \frac{1}{2}(x_1 + x_2 + x_3), y_2 = \frac{1}{2}(x_1 - x_2 + x_3)$, 则

$${y_1}^2 - {y_2}^2 = x_1x_2 + x_2x_3$$

(1) (1) 若n是偶数,则

$$\begin{cases} y_1=\frac{1}{2}(x_1+x_2+x_3) \\ y_2=\frac{1}{2}(x_1-x_2+x_3) \\ y_3=\frac{1}{2}(x_3+x_4+x_5) \\ y_4=\frac{1}{2}(x_3-x_4+x_5) \\ \ldots\ldots \\ y_{n-3}=\frac{1}{2}(x_{n-3}+x_{n-2}+x_{n-1}) \\ y_{n-2}=\frac{1}{2}(x_{n-3}-x_{n-2}+x_{n-1}) \\ y_n=\frac{1}{2}(x_{n-1}-x_n) \end{cases}$$

$$c_1=\frac{1}{2}\left(\begin{array}{cc|cc|c|cc|cc} 1 & -1 & 1 & & & & & & \\ 1 & -1 & 1 & & & & & & \\ \hline & & 1 & 1 & 1 & & & & \\ & & 1 & -1 & 1 & & & & \\ \hline & & & & \cdots & & & & \\ \hline & & & & & 1 & 1 & & \\ & & & & & 1 & -1 & & \\ \hline & & & & & & & 1 & 1 \\ & & & & & & & 1 & -1 \end{array}\right)$$

即， $Y=C_1X$

显然 $|C_1|=\frac{1}{2^n}(-2)^{\frac{1}{2}}\neq 0$, 令 $C=C_1^{-1}$

则 X=CY 使

$$f=y_1^2-y_2^2+y_3^2-y_4^2+\ldots.+y_{n-3}^2-y_{n-2}^2+y_{n-1}^2-y_n^2$$

$\Delta(ii)$ 若n为奇数,同理

补P_{234}.1③)(也可直接证明,或归纳证明)

P234 补 1.④ $f=\sum_{i=1}^{n}(x_i-\bar{X})^2, \bar{X}=\frac{1}{n}\sum_{i=1}^{n}x_i$

$$\begin{pmatrix} y_1 \\ y_2 \\ \dots \\ y_{n-1} \\ y_n \end{pmatrix} = y = \frac{1}{n}\begin{pmatrix} n-1 & -1 & -1 & \dots & -1 \\ -1 & n-1 & -1 & \dots & -1 \\ \dots & \dots & \dots & \dots & \dots \\ -1 & -1 & \dots & n-1 & -1 \\ 0 & 0 & \dots & \dots & 1 \end{pmatrix} X = \frac{1}{n} C_3 X \text{或} X = (\frac{1}{n}c_3)^{-1} y$$

$$= \begin{pmatrix} 2 & 1 & 1 & \dots & 1 \\ 1 & 2 & 1 & \dots & 1 \\ \dots & \dots & \dots & \dots & \dots \\ 1 & 1 & \dots & 2 & 1 \\ 0 & 0 & \dots & 0 & 1 \end{pmatrix} y$$

令 .

$\because y_i = x_i - \frac{1}{n}\sum_{i=1}^{n} x_i = x_i - \overline{x}, y_n = x_n,$ $\sum y_i = \sum x_i - (n-1)\overline{x} = \overline{x}$

$\therefore f = \sum_{i=1}^{n-1} y_i^2 + (x_n - \overline{x})^2 = \sum_{i=1}^{n-1} y_i^2 + (y_n - \sum_{i=1}^{n} y_i)^2 = 2(\sum_{i=1}^{n-1} y_i^2 + \sum_{1 \le i < j \le n-1}^{n} y_i y_j)$

参照P_{234}.1③(5.75.5.3)令

$$Z = C_4 Y = \begin{pmatrix} 1 & \frac{1}{2} & \frac{1}{2} & \dots & \frac{1}{2} & 0 \\ 0 & 1 & \frac{1}{3} & \dots & \frac{1}{3} & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1 & \frac{1}{n-1} & 0 \\ 0 & 0 & \dots & 0 & 1 & 0 \\ 0 & 0 & \dots & \dots & 0 & 1 \end{pmatrix} Y$$

则 $f = 2z_1^2 + \frac{3}{2}z_2^2 + \frac{4}{3}z_3^2 + \dots + \frac{n}{n+1}z_{n-1}^2$

其中 $x = (\frac{1}{n}c_3)^{-1} y = (\frac{1}{n}c_3)^{-1} c_4^{-1} y = n(c_4 c_3)^{-1} y$

矩阵验算略.

P_{234}补 2,不妨设 秩(A)=r,且$\begin{vmatrix} a_{11} & \dots & a_{1r} \\ \dots & \dots & \dots \\ a_{r1} & \dots & a_{rr} \end{vmatrix} \ne 0(\text{左上角}r\text{阶子式})$

$$\therefore \text{作}X = C_1 Y, \text{其中}C_1 = \begin{pmatrix} a_{11} & \dots & a_{1r} & \dots & a_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{r1} & \dots & a_{rr} & \dots & a_{rn} \\ 0 & \dots & 0 & 1 & 0 \\ \dots & \dots & \dots & \dots & \dots \\ 0 & \dots & \dots & 0 & 1 \end{pmatrix}$$

那么, $f = y_1^2 + y_2^2 + \dots y_r^2 + \delta_{r+1}^2 + \dots + \delta_s^2 (\delta_i \text{为} y_1, \dots y_r \text{的一次式})$

作一个$f_1(y_1,y_2,\ldots y_r)=f$被为$r$元二次型�那么�任取�$c_1,c_2,\ldots c_r)\neq 0$

那么，必有$f_1(c_1,c_2,\ldots c_r)=f(c_1,\cdots c_{r,}\cdots 0)>0,\therefore f_1$是一个$r$元正定二次型

$$\begin{pmatrix} y_1 \\ y_2 \\ \ldots \\ y_r \end{pmatrix}=G\begin{pmatrix} z_1 \\ z_2 \\ \ldots \\ z_r \end{pmatrix}\text{使}f_1(y_1,y_2,\ldots y_r)=c_1{}^2+c_2{}^2+\ldots+z_r{}^2$$

$$\text{令}\begin{pmatrix} y_1 \\ y_2 \\ \ldots \\ y_n \end{pmatrix}=\begin{pmatrix} G & o \\ o & E_{n-r} \end{pmatrix}\begin{pmatrix} z_1 \\ \ldots \\ z_r \\ \ldots \\ z_n \end{pmatrix},C_2=\begin{pmatrix} G & o \\ o & E_{n-r} \end{pmatrix}\text{可逆}$$

则$f=y_1{}^2+\ldots+y_r{}^2+\delta_{r+1}{}^2+\ldots+\delta_s{}^2$

且$X=C_1Y=C_1C_2Z=CZ(C=C_1C_2$可逆�

必有$\therefore f$的正惯性指数$=r=$秩(A)

P$_{234}$补 3(先讲补 2), $f=l_1{}^2+\ldots+l_p{}^2-l_{p+1}{}^2-\ldots-l_{p+q}{}^2$

证:设$l_i=a_{i1}x_1+a_{i2}x_2+\ldots+a_{in}x_n$

并设X=CY,(C可逆)使 $f=y_1{}^2+y_2{}^2+\ldots+y_{p'}{}^2-y_{p'+1}{}^2-\ldots-y_{p'+q'}{}^2$

$$p'>p\text{作线性方程组}\left\{\begin{array}{l} l_1=0 \\ \ldots \\ l_p=0 \\ \ldots \\ y_{p'+1}=0 \\ \ldots \\ y_n=0 \end{array}\right\}$$

那么　反设

$y_i=b_{i1}x_i+\ldots+b_{in}x_n$

$Y=C^{-1}X$

共有 $p+(n-p')=n-(p'-p)<n$的方程

存在非零时,

$$X_0=\begin{pmatrix} c_1 \\ \ldots \\ c_n \end{pmatrix}\neq 0, y_0=c^{-1}X_0\neq 0,\because y_{p'+1}=\ldots=y_n=0\therefore y_0\text{的前}P'\text{个分量不全为}0$$

$\therefore$一方面$f=-l_{p+1}{}^2-\ldots,-l_{p+q}{}^2\leq 0$

另一方面 $f=y_1{}^2+\ldots+y_{p'}{}^2>0$($i$不全为0)

矛盾,所有 $p'\leq p$

同理,负惯性指数$q' \le q$

另推论:如本例形式二次型,例$p+q \ge r$(秩)

p_{235}补4证明： $\because T'AT = A = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix}, T = \begin{pmatrix} E & X \\ o & E \end{pmatrix}$

$$= \begin{pmatrix} E & X \\ o & E \end{pmatrix} \begin{pmatrix} A_{11} & A_{11}X + A_{12} \\ A_{21} & A_{21} + A_{22} \end{pmatrix} + \begin{pmatrix} E & o \\ X' & E \end{pmatrix} \begin{pmatrix} A_{11} & A_{11}x + A_{12} \\ A_{21} & A_{21}x + A_{22} \end{pmatrix}$$

$$= \begin{pmatrix} A_{11} & A_{11}x + A_{12} \\ x'A_{11} + A_{21} & * \end{pmatrix}$$

$A_{11}x + A_{12} = 0$则$x = -A_{11-1}A_{12}, (\because A_{12} = A_{21})$

$\therefore x'A_{11} + A_{21} = (-A_{12}', A_{11}^{-1})A_{11} + A_{21} = -A_{21}A_{11}^{-1}A_{11} + A_{21} = 0$

设

取 $T = \begin{pmatrix} E & -A_{11}^{-1}A_{12} \\ o & E \end{pmatrix}$即合要求

P_{235},补 5,若n=1,显然A=0

若 n=2,A=0,显然

$$A \ne o, 则\begin{pmatrix} 0 & a \\ -a & 0 \end{pmatrix}', \begin{pmatrix} \frac{1}{a} & 0 \\ 0 & 1 \end{pmatrix}' \begin{pmatrix} 0 & a \\ -a & 0 \end{pmatrix} \begin{pmatrix} \frac{1}{a} & 0 \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}成立$$

【】

由于A_2仍为反对称

故归纳假设A_2: $T'_2 A_2 T_2 = \begin{pmatrix} 0 & 1 & & & & & & \\ -1 & 0 & & & & & & \\ & & \cdots & & & & & \\ & & & 0 & 1 & & & \\ & & & -1 & 0 & & & \\ & & & & & 0 & & \\ & & & & & & \cdots & \\ & & & & & & & 0 \end{pmatrix}$

$$\therefore 取 C=P_{(s,t)}P_{(t,2)}T\begin{pmatrix}\frac{1}{a}&&&\\&1&&\\&&\cdots&\\&&&1\end{pmatrix}\begin{pmatrix}E_2&0\\0&T_2\end{pmatrix}则$$

$$C^{'}AC=\begin{pmatrix}0&1&&&&&&\\-1&0&&&&&&\\&&\cdots&&&&&\\&&&0&1&&&\\&&&-1&0&&&\\&&&&&0&&\\&&&&&&\cdots&\\&&&&&&&0\end{pmatrix}$$

证毕.

P_{235}补,6 由习题第 10 题(5.77.7.2),一定存在 $C_1>0,当 t>c_2 时$
C_1E-A 永为正定

$C>\max\{C_1,C_2\}那么同时 CE+A,CE-A 正定,$

$即要 X_0\neq 0,x_0'(CE+A)X_0>0\Rightarrow 2CX_0'X_0<X_0'AX_0$

$X_0'(CE-A)X_0>0\Rightarrow CX'_0X_0<X_0'AX_0$

$即 -CXo'Xo<X'_0AXo<CXo'Xo$

取 $\therefore 对每个 X,有 |X'AX|<CX'X$

P_{235}补 7, 1) $T=\begin{pmatrix}1&&&*\\&1&&\cdots\\&&1&\\&\cdots&&\cdots\\0&&&1\end{pmatrix}$, $B=T'AT$

将,T分块 $T=\begin{pmatrix}T_1&T_3\\0&T_2\end{pmatrix},A=\begin{pmatrix}A_1&A_2\\A_{2'}&A_3\end{pmatrix}其中,T_1,A_1为K阶方阵.$

则 B 的第 K 个顺序主子式的矩阵为

$$T'AT=\begin{pmatrix}T_1'&0\\T_3'&T_2'\end{pmatrix}\begin{pmatrix}A_1&A_2\\A_2'&A_3\end{pmatrix}\begin{pmatrix}T_1&T_3\\0&T_2\end{pmatrix}=\begin{pmatrix}T_1'&0\\T_3'&T_2\end{pmatrix}\begin{pmatrix}A_1T_1&*\\A_2'T_1&*\end{pmatrix}=\begin{pmatrix}T_1'A_1T_1&*\\*&*\end{pmatrix}$$

的左上角k阶方阵,即为 $T_1'A_1T_1$

$\therefore B的第k个顺序主子式=|T_1'A_1T_1|=|T_1|^2|A_1|=|A_1|,为A的第k个顺序主子式.证毕$

2)归纳证明,*n=1* 显然,设 *n-1* 成立,考虑 *n* 情形

设 $A=\begin{pmatrix}A_1&\alpha\\\alpha'&a_{\cos}\end{pmatrix}由A_1满足条件,存在T_1特殊上三角,使D_1=T_1'A_1T_1为对角$

设 $G=\begin{pmatrix}T_1 & 0\\ 0 & 1\end{pmatrix}$仍为特殊上三角�使$G'A'G=\begin{pmatrix}D_1 & T_1'\alpha\\ \alpha'T_1 & a_{nn}\end{pmatrix}=B$

$\because |D_1|=|T_1|^2|A_1|\neq 0 \therefore D_1$可逆,

又 $H=\begin{pmatrix}E_{n-1} & -D^{-1} & T_1'\alpha\\ 0 & 1\end{pmatrix}$仍为特殊上三角, 且

$H'BH=\begin{pmatrix}E_{n-1} & 0\\ -\alpha'T_1D_1^{-1} & 1\end{pmatrix}\begin{pmatrix}D_1 & 0\\ \alpha^{'}\beta T_1 & a_{nn-x}\end{pmatrix}=\begin{pmatrix}D_1 & 0\\ 0 & 6\end{pmatrix}=D$,为对角矩阵

故取,C=GH 仍为特殊上三角,且 C’AC=D 为对角,证毕.

3)

$\because A$的顺序主子式$P_1 \; CP_2..CP\; n$全大于0,故存在特殊上三角T使,$D=T'AT$为对角,于是

D与A的顺序主子式值相等,设$D=\begin{pmatrix}d_1 & & & \\ & d_2 & & \\ & & \dots & \\ & & & d_n\end{pmatrix}$

则 $d_1,d_2,\dots d_k=p_k>0,k=1,2,\dots n,$推出$d_1,d_2,\dots d_n>0$

所以 D 正定,即 A 正定,证毕.

$$f=\begin{vmatrix}A & y\\ y' & 0\end{vmatrix}=\left|\begin{pmatrix}A & y\\ y' & 0\end{pmatrix}\begin{pmatrix}E & -A^{-1}y\\ 0 & 1\end{pmatrix}\right|=\begin{vmatrix}A & 0\\ y' & -y'A^{-1}y\end{vmatrix}=(-|A|)\cdot y'A^{-1}y$$

P_{236}补 8, 1),

$\because A$正定 i已知 j .CA^{-1}正定 i见习题第11题$P5.76.6.4$),故对任一组$y\neq 0$值.

$y'A^{-1}>0,\therefore f(y_1,y_2,\dots y_n)=(-|A|)y'A^{-1}y<0,(\because |A|>0)$

$\therefore f$是负定二次型

2)设 $A=\begin{pmatrix}A_1 & \alpha\\ \alpha' & a_{nn}\end{pmatrix},B_1=\begin{pmatrix}A_1 & \partial\\ \partial' & 0\end{pmatrix},B_2=\begin{pmatrix}A_1 & 0\\ \alpha' & a_{nn}\end{pmatrix}$

$\therefore |A|=|B_1|+|B_2|=(-|A_1|)\partial'A_1^{-1}\partial+a_{nn}|A_1|\leq a_{nn}|A_1|=q_{nn}p_{n-1}$

$\because A1$仍然证定 .$C|A_1|\leq a_{n-1n-1}p_{n-1}$

如此下去 C则$|A|\leq a_{nn}p_{n-1}\leq a_{nn}q_{n-1n-2}\leq a_{nn}\dots a_{33}a_{22}p_1=a_{nn}\dots a_{22}a_{11}$

3) 即$|A|\leq a_{11}a_{22},\dots a_{nn}$

作$A=T'T=T'ET$,则A正定且$a_{ii}=\sum_{k=1}^{n}t_{ki}{}^2$

4) $\therefore |A|=|T|^2\leq\prod_{i=1}^{n}a_{ii}=\prod_{i=1}^{n}\sum_{k=1}^{n}t_{ki}{}^2=\prod_{i=1}^{n}(t_{1i}{}^2+t_{2i}{}^2+\dots+t_{ni}{}^2).$

P_{236}补9（必要性）

$$A \geq 0 \Rightarrow C\text{可逆}, C'AC = \begin{pmatrix} d_1 & & \\ & \ddots & \\ & & d_n \end{pmatrix} \geq 0. \therefore di \geq 0$$

$$\therefore |C|^2 |A| = d_1 d_2 \cdots d_n \geq 0 \therefore |A| \geq 0.$$

作$g(x_{i_1}, \ldots x_{i_2}, \ldots x_{i_k}) = f(0 \ldots x_{i_1}, \ldots 0 x_{i_2}, \ldots x_{i_k} 0)$

则$g(x_{i_1}, \ldots x_{i_k})$半正定，$g$的矩阵为$\begin{pmatrix} a_{i_1 i_1} & \ldots & a_{i_1 i_k} \\ \ldots & \ldots & \ldots \\ a_{i_k i_1} & \ldots & a_{i_k i_k} \end{pmatrix} = A_1$

$$\therefore A_1 \geq 0 \therefore |A_1| \geq 0$$

$$D = \begin{vmatrix} a_{11+\lambda} & a_{12} & \ldots & a_{1n} \\ a_2 1 & a_{22+\lambda} & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{n2} & \ldots & a_{nn+\lambda} \end{vmatrix} = \lambda^n + a_1 \lambda^{n-1} + \ldots + a_k \lambda^{n-k} + \ldots + a_n \text{中}\lambda^{n-k}\text{的系数}a_k$$

这样取到在 0 中主对角线上任取n-k项中的λ^{n-k}的系数a_k项所在的行和列,得一个K级子式(含入)DK,由于是λ^{n-k}的系数 故K的子式D中只能取所有的常数项 即令DK中的$\lambda = 0$,这正是D的一个K级主子式,要是λ^{n-k}的系数中的一元,故a_k为D的所有k阶主子式之和,如

$$a_1 = a_{11} + a_{22} + \ldots + a_{nn}\text{等}.$$

现在考虑任意$\varepsilon > 0, A + \varepsilon E$,它的$m$阶顺序主子式,为$A$的右上角的m阶方阵,$A_r$作：

$$|A_k + \varepsilon Ek| = \varepsilon^k + b_1 \varepsilon^{k-1} + \ldots + b_k$$

由于ε^{k-i}的系数b_i是A_k的一切i阶主子式之和,而A_k的主子式仍为A的主子式,

由充分条件,$b_i \geq 0, \therefore |A_k + \varepsilon E_k| \geq \varepsilon_k > 0$

因此$A + \varepsilon E$正定,故对任何$X \neq 0, X'(A + \varepsilon E)X > 0$

$\therefore \lim\limits_{\varepsilon \to \infty} X'(A + \varepsilon E)Z = X'AX \geq 0$(边续性)

所以A半正定.

第六章 线性空间习题解答

P267.1 设$M \subseteq N$,证明:$M \cap N = M, M \cup N = N$

证：$\forall x \in M \Rightarrow x \in N = M \Rightarrow x \in M \cap N \Rightarrow M \subseteq M \cap N$

$\forall x \in M \cap N \Rightarrow x \in M \Rightarrow M \cap N \subseteq M, \therefore M \cap N \subseteq M$

$\therefore M \cap N = M$

又$\forall x\in N\Rightarrow x\in M\bigcup N\Rightarrow N\subset M\bigcup N$

$\forall x\in M\bigcup N\Rightarrow x\in N$或$x\in M\subseteq N\Rightarrow x\in N$

$\therefore M\bigcup N=N$

P267.2 证：①$M\bigcap(N\bigcup L)=(M\bigcap N)\bigcup(M\bigcap L)$

②$M\bigcup(N\bigcap L)=(M\bigcup N)\bigcap(M\bigcup L)$

①：

证(1)：$x\in$左$\Leftrightarrow x\in M$且$x\in N\bigcup L\Leftrightarrow x\in M$且$(x\in N$或$x\in L)\Leftrightarrow x\in M\bigcap N$或$x\in M\bigcap L$

$\Leftrightarrow x\in$右$\Rightarrow$反过来。证毕

证(2)：$x\in$左$\Leftrightarrow\in M$或$x\in N\bigcap L\Leftrightarrow x\in M$或$(x\in N$且$x\in L)$

$\Leftrightarrow x\in M\bigcup N$且$x\in M\bigcup L\Leftrightarrow x\in$右。证毕

P_{267}.3①不做成,因为 2 个n次多项式相加不一定是n次多项式,如

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

$$f(A)+g(A)=h_1(A),(h_1(x)=f(x)+g(x)\text{为多项式)}$$

②做成,因为$kf(A)=h_2(A),(h_2(x)=kf(x)$为多项式)

③做成. 因为实对称(反对称, 上三角,下三角)之和之倍数仍为实对称(反对称, 上三角,下三角)故做成线性空间

④不做成,设$V=\{\alpha\,|\,\alpha$为平面上不平行β的向量$\}$

⑤不做成,违反定义 3.(5)$\because 1\alpha=\alpha$，但这里$1\alpha=0$。取$\alpha\neq0$即得矛盾。

P267.3⑤

$$(a_1,b_1)\oplus(a_2,b_2)=(a_1+a_2,b_1+b_2+a_1a_2)$$

$$k\circ(a_1,b_1)=(ka_1,kb_1+\frac{1}{2}k(k-1)a_1{}^2$$

解: 显然V非空 1^0

以及 2 个封闭的代数运算2^0

验证3^0先设$\alpha=(a_1,b_2),\beta=(a_2,b_2),r=(a_3,b_3)$,及$k,t\in R$

$(1)\alpha\oplus\beta=\beta\oplus\alpha=(a_2+a_1,b_2+b_1+a_2a_1)$

$(2)(\alpha\oplus\beta)+r=((a_1+a_2)+a_3,(b_1+b_2+a_1a_2)+b_3+(a_1+a_2)a_3$

$......................=(a_1+a_2+a_3,b_1+(b_2+b_3+a_2a_3)$

$....\alpha\oplus(\beta\oplus r)=(a_1+(a_2+a_3),b_1=(b_2+(b_2+b_3+a_2a_3)+a_1(a_2+a_3)$

$.....................=(a_1+a_2+a_3,b_1+b_2+b_3+a_2a_3+a_1a_2+a_1a_3)=(\alpha+\beta)+r$

$(3)0=(0,0),\alpha+0=(a_1+0,b_1+0+a_10)=(a_1,b_1)=\alpha$

$(4)\alpha$的负为$-\alpha=(-a_1,a_1{}^2-b_1)$

$..........\alpha\oplus(-\alpha)=)a_1+(-a_1),b_1+(a_1{}^2-b_1)+a_1(-a_1))=(0,0)=0$

$$(5)1\circ\alpha=(1\circ a_1,1\circ b_1+\frac{1}{2}1\circ(1-1)a_1{}^2)=(a_1,b_1)=\alpha$$

$$(6)k\circ(l\circ\alpha)=k\circ(la_1,lb_1+\frac{1}{2}l(l-1)a_1{}^2$$

$$...............=(kla_1,k(lb_1+\frac{1}{2}k(k-1)a_1{}^2)+\frac{1}{2}k(k-1)(la_1)^2)$$

$=(kla_1+klb+\frac{1}{2}kla_1^2(l-1+(k-1))$

=（kla_1,klb_1+ $\frac{1}{2}kl((k-1)a_1^2)$

=kl∘ α

(7)(k+l)∘ α **=（（k+1）a_1,(k+l)b_1+** $\frac{1}{2}(k+l)(k+l-1)a_1^2)$

=((k+1)a_1,(k+l)b_1+ $\frac{1}{2}(k^2+l^2+2kl-k-l)a_1^2)$

$=(ka_1+la_1,kb_1+\frac{1}{2}k(k-1)a_1^2+(b_1+\frac{1}{2})l(l-1)a_1^2+ka_1\cdot la_1)$

$=k\circ\alpha\oplus l\circ\alpha$

(8)

$k\circ(\alpha\oplus\beta)=k\circ(a_1+a_2,b_1+b_2+a_1a_2)=(k(a_1+a_2),k(b_1+b_2+a_1a_2+\frac{1}{2}k(k-1)(a_1+a_2)^2)$

$=(ka_1+ka_2,kb_1+\frac{1}{2}k(k-1)a_1^2+kb_2+\frac{1}{2}k(k-1)a_2^2+ka_1a_2+k(k-1)a_1a_2)$

$=(ka_1+ka_2,(kb_1+\frac{1}{2}k(k-1)a_1^2)+(kb_2+\frac{1}{2}k(k-1)a_2^2+(k^2a_1a_2))$

$=(ka_1,kb_2+\frac{1}{2}k(k-1)a_1^2)\oplus(ka_2kb_2+\frac{1}{2}k(k-1)a_2^2)=\alpha\oplus\beta$

满足 **3,**故 **V** 是一个线性空间

不做成。违反分配律，$\forall\alpha\neq 0$,则会有$\alpha=2.\alpha=(1+1).\alpha=1.\alpha+1.\alpha=\alpha+\alpha$

⑥$\Rightarrow\alpha=0$,矛盾

P$_{267,3}$⑧V=R^+ P=R ***a*** $\oplus$ *b=ab* $k\circ a=a^k$

解**:V**非是①关于$\oplus$∘封闭②

任取**a.b.c**$\in R^+,k,l\in R$

(1)*a* $\oplus$ *b=b* $\oplus$ *a=ba*

(2)*(a* $\oplus$ ***b)*** $\oplus$ ***c=(ab)c=a(bc)=a*** $\oplus$ ***(b*** $\oplus$ ***c)***

(3)零元 ***0=1, a*** $\oplus$ ***0=a•1=a***

(4)负元-a=$\frac{1}{a}$,a$\oplus$(-a)=a•$\frac{1}{a}$=1=0

(5)*1∘a=a^1=a*

(6)k∘(l∘a)=k∘(a^1)=(a^1)^k=a^{lk}=(lk)∘a

(7)(k+l)∘a=a$^{(k+l)}$=a^k•a^l=a^k $\oplus$ ***a^l=k∘ a*** $\oplus$ ***1∘ a***

(8)k∘*(a* $\oplus$ ***b)=k∘(ab)=(ab)^k=a^{k}b^k***

= a^k $\oplus$ ***b^k= k∘ a*** $\oplus$ ***k∘ b***

都成立**,**故**R$^+$**关于$\oplus$∘做成**R**上的向量空间

P$_{268}$.4①k0=0

$k0=\alpha$, 则 $\alpha=k0=k(0+0)=k0+k0=\alpha+\alpha$

证:设 $\therefore \alpha=\alpha+(-\alpha)=0$

即 k0=0

4② $k(\alpha-\beta)=k\alpha-k\beta$

$\because 0=\alpha+(-\alpha)=\alpha+(-1)\alpha=[1+(-1)].\alpha=0.\alpha=0$

$\therefore (-1)\alpha=-\alpha$

故 $k(\alpha-\beta)=k(\alpha+(-1)\beta)=k\alpha+k(-1)\beta=k\alpha+(-1)(k\beta)$

$=k\alpha+(-(k\beta))=k\alpha-k\beta$

P_{268},5 实函数空间F中,0 是 0 函数 0(x),∀ x∈定义域O(x)=0,

于是**k•1+** $l\cdot\cos^2 t+m\cdot\cos 2t$

$=k\cdot 1+l\cos^2 t+m(2\cos^2 t-1)$

$=(k-m)\cdot 1+(l+2m)\cos^2 t$

可取,m=1,k=1,l=-2,则

$1\cdot 1+(-2)\cos^2 t+1\cdot\cos 2t=0\cdot(x)$

∴ $1.\cos^2 t,\cos 2t$ 线性相关

$P_{268.6}$在P[x]中,0 元是 0 多项式(即系数全为 0 的多项式)

证:∵ $(f_1,f_2,f_3)=1,(f_1,f_2)\neq 1,(f_2,f_3)\neq 1,(f_2,f_1)\neq 1,$

设 $a_1 f_1(x)+a_2 f_2(x)+a_3 f_3(x)=0$, 不妨设 $a_1\neq 0$

$\therefore f_1(x)-(-\frac{a_2}{a_1})f_2(x)+(-\frac{a_3}{a_1})f_3(x)$

$\because (f_2,f_3)\neq 1$, 被 $(f_2(x),f_3(x))=d(x)$,

那么*d(x)*整除 f_2,f_3 **的组合,故** $d(x)\mid f_1(x)$, **于是有**

$d(x)\mid(f_1(x),f_2(x),f_3(x))$

与 $(f_1,f_2,f_3)=1$ **矛盾!**

P268,7① $\varepsilon_1=(1,1,1,1),\varepsilon_2=(1,1,-1,-1),\varepsilon_3=(1,-1,1,-1),\varepsilon_4=(1,-1,-1,1),\xi=(1,2,1,1)$

设 $\xi=x_1\varepsilon_1+x_2\varepsilon_2+x_3\varepsilon_3+x_4\varepsilon_4$ 得方程解

$$\begin{pmatrix}1&1&1&1\\1&1&-1&2\\1&-1&1&1\\1&-1&-1&1\end{pmatrix}\Rightarrow\begin{pmatrix}x_1\\x_2\\x_3\\x_4\end{pmatrix}=\begin{pmatrix}1&1&1&-1\\1&1&-1&-1\\1&-1&1&-1\\1&-1&-1&1\end{pmatrix}^{-1}\begin{pmatrix}1\\2\\1\\1\end{pmatrix}=\begin{pmatrix}\because A^2=4E\\ \therefore A^{-1}=\frac{1}{4}A\end{pmatrix}$$

$$=\frac{1}{4}\begin{pmatrix}1&1&1&1\\1&1&-1&-1\\1&-1&1&-1\\1&-1&-1&1\end{pmatrix}\begin{pmatrix}1\\2\\1\\1\end{pmatrix}=\frac{1}{4}\begin{pmatrix}5\\1\\-1\\-1\end{pmatrix}=\begin{pmatrix}5/4\\1/4\\-1/4\\-1/4\end{pmatrix}$$

坐标为$\left(\frac{5}{4},\frac{1}{4},-\frac{1}{4},-\frac{1}{4}\right)$

$P_{268}.7.(2)\varepsilon_1=(1,1,0,1),\varepsilon_2=(2,1,3,1),\varepsilon_3=(1,1,0,0),\varepsilon_4=(0,1,-1,-1)$，$\xi=(0,0,0,1)$

设$\xi=x_1\varepsilon_1+x_2\varepsilon_2+x_3\varepsilon_3+x_4\varepsilon_4$,得

$$\left\{\begin{array}{l}x_1+x_2+x_3=0\\x_1+x_2+x_3+x_4=0\\x_2+x_4=0\\x_1+x_2=x_4=0\end{array}\right\}\qquad\begin{pmatrix}1&2&1&0&0\\1&1&1&1&0\\0&3&0&-1&0\\1&1&0&-1&1\end{pmatrix}\to\begin{pmatrix}1&2&1&0&0\\0&-1&0&1&0\\0&-3&0&-1&0\\0&-1&-1&-1&1\end{pmatrix}$$

$$\to\begin{pmatrix}1&0&1&2&0\\0&1&0&-1&0\\0&0&0&2&0\\0&0&-1&-2&1\end{pmatrix}\to\begin{pmatrix}1&0&0&0&1\\0&1&0&-1&0\\0&0&1&2&-1\\0&0&0&1&0\end{pmatrix}\to\begin{pmatrix}1&0&0&0&1\\0&1&0&0&0\\0&0&1&0&-1\\0&0&0&1&0\end{pmatrix}$$

唯一解得$x_1=1,x_2=0,x_3=-1,x_4=0$

$\therefore\xi=\varepsilon_1-\varepsilon_2$

在此基下的 坐标为$(1,0,-1,0)$

P₂₆₈. 8① $P^{n\times n}$的一组是$E_{ij},i.j=1,2,...,n,$共有n^2个(矩阵)元素

它们线性无关 $\because\sum_{i,j=1}^{n}a_{ij}E_{ij}=0\Rightarrow A=(a_{ij})=0\Rightarrow\forall i,j,a_{ij}=0$

且任何 $B=(b_{ij})\in P^{n\times n}$,则$B=\sum_{i,j=1}^{n}b_{ij}E_{ij}$

$\dim P^{n\times n}=n^2$,它的一个基是$E_{ij},i,j=1,2,...,n$

8② $P^{n\times n}$中全体对称矩阵集合S(P)，它的一个基是$E_{ij}+E_{ji},i\le j$

$$\dim S(P)=\frac{1}{2}n(n+1)$$

$P^{n\times n}$中全体对称矩阵集合K(P)，它的一个基是$E_{ij}-E_{ji},i<j$

$$\dim K(P)=\frac{1}{2}n(n-1)$$

$P^{n\times n}$中全体上三角矩阵集合$U(T)$,它的一个基是$E_{ij},i\le j$

$$\dim U(T)=\frac{1}{2}n(n+1)$$

$P^{n\times n}$ 中全体真下 三角矩阵集合$D^{+}(T)$,它的一个基是$E_{ij}, i>j$

$$\dim D(T)=\frac{1}{2}n(n-1)$$

8②中，θ,零元是1，取一个$a>0, a\neq 1$,则$a\in IR^{+}$

那么$\forall b\in R^{+}$,取$k=\log_a b(\because b=k\circ a=a^k\Rightarrow \lg b=k.\lg a$

$\therefore b=(\log_a b)\circ a=a^{\log_a b}$

所以a是R^{+}的一个基$\dim_R R^{+}=1$

$$P_{268}.8(4), V=\left\{ f(A)\ \middle|\ f(x)\in R[x], A=\begin{pmatrix}1 & & \\ & \omega & \\ & & \omega^2\end{pmatrix}\right., \omega=\frac{-1+\sqrt{3}i}{2}$$

解：因为ω^3=1

所以 $$A^2=\begin{pmatrix}1 & & \\ & \omega^2 & \\ & & \omega^4\end{pmatrix}=\begin{pmatrix}1 & & \\ & \omega^2 & \\ & & \omega\end{pmatrix}.A^3=\begin{pmatrix}1 & & \\ & 1 & \\ & & 1\end{pmatrix}=E$$

故任设 $f(x)\in R[x], f(x)=a_0+a_1x+a_2x^2+\cdots+a_nx^n$

则 $f(A)=(a_0+a_3+a_6+\cdots)E+(a_1+a_4+a_7+\cdots)A+(a_2+a_5+a_8+\cdots)A^2$

故 $f(A)=b_0E+b_1A+b_2A^2$

∴E, A, A^2可表示V中所有元素。

如果 $$xE+yA+zA^2=0\Rightarrow\begin{cases}x+y+z=0\\ x+\omega^1y+\omega^2z=0\\ x+\omega^2y+\omega E=0\end{cases}$$

∵系数行列式 $$\begin{vmatrix}1 & 1 & 1\\ 1 & \omega & \omega^2\\ 1 & \omega^2 & \omega\end{vmatrix}=3(\omega^2-\omega)\neq 0,\text{所以}x=y=z=0\text{只有零解}$$

即，***E***、***A***、A^2线性无关，由定理 **1**

dimV=3, 它的一个基是***E***、***A***、A^2

P269.9① $\varepsilon_1=(1,0,0,0),\varepsilon_2=(0,1,0,0),\varepsilon_3=(0,0,1,0),\varepsilon_4=(0,0,0,1),\xi=(x_1,x_2,x_3,x_4)$

$\eta_1=(2,1,-1,1),\eta_2=(0.3.1.0)\eta_3=(5.3.2.1),\eta_4=(6.6.1.3),$

解 $\xi=x_1\varepsilon_1+x_2\varepsilon_2+x_3\varepsilon_3+x_4\varepsilon_4$

$\therefore \varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4\to\eta_1,\eta_2,\eta_3,\eta_4,\qquad y=(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)Ay$

∴坐标y为 $$y=A^{-1}\begin{pmatrix}x_1\\x_2\\x_3\\x_4\end{pmatrix}=\begin{pmatrix}4/9 & 1/3 & -1 & -1/9\\ 1/27 & 4/9 & 1/3 & -23/27\\ 1/3 & 0 & 0 & -2/3\\ -7/27 & -1/9 & 1/3 & -6/27\end{pmatrix}\begin{pmatrix}x_1\\x_2\\x_3\\x_4\end{pmatrix}$$

（A^{-1}计算附下页）

$$(A,E)\to\begin{pmatrix}2&0&5&6\\1&3&3&6\\-1&1&2&1\\1&0&1&3\end{pmatrix}\to\begin{pmatrix}1&0&1&3\\0&1&3&4\\0&3&2&3\\0&0&3&0\end{pmatrix}\begin{pmatrix}0&0&0&1\\0&0&1&1\\0&1&0&-1\\1&0&0&-2\end{pmatrix}\to\begin{pmatrix}1&0&1&3\\0&1&3&4\\0&0&-7&-9\\0&0&3&0\end{pmatrix}$$

$$\begin{pmatrix}0&0&0&0\\0&1&0&0\\0&0&1&0\\1&0&0&1\end{pmatrix}\to\begin{pmatrix}1&0&0&-6\\0&1&0&4\\0&0&-1&-9\\0&0&3&0\end{pmatrix}\begin{pmatrix}2&1&-3&-7\\-1&0&1&3\\2&1&-3&-8\\1&0&0&-2\end{pmatrix}\to\begin{pmatrix}1&0&0&-6\\0&1&0&4\\0&0&1&9\\0&0&0&-27\end{pmatrix}$$

$$\begin{pmatrix}2&1&-3&-7\\-1&0&1&3\\-2&-1&3&8\\7&3&-9&-26\end{pmatrix}\to\begin{pmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{pmatrix}\to\begin{pmatrix}4/9&1/3&-1&-11/9\\1/27&4/7&-23/27&-23/27\\1/3&0&-2/3&-2/3\\-7/29&-1/9&\frac{1}{3}&26/27\end{pmatrix}$$

P_{269}. 9. (2) 求由 $\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4\to\eta_1,\eta_2,\eta_3,\eta_4$ 的过渡矩形, 并求多在 $\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4$ 下的坐标.

$\varepsilon_1=(1,2,-1,0)$ $\qquad\eta_1=(2,1,0,1)$

$\varepsilon_2=(1,-1,1,1)$ $\qquad\eta_2=(0.1,2,2)$

$\varepsilon_3=(-1,2,2,1,1)$ $\qquad\eta_3=(-2,1,1,2)$

$\varepsilon_4=(-1,-1,0,1)$ $\qquad\eta_4=(1,3,1,2)$ $\qquad\xi=(1,0,0,0)$

解 $\because(\eta_1,\eta_2,\eta_3,\eta_4)=(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)T$ 因此.

$(\eta_1,\eta_2,\eta_3,\eta_4,\xi)=(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)(T,X)$

$\therefore(T,X)=A^{-1}B$

$$\therefore B=\begin{pmatrix}2&0&-2&1&1\\1&1&1&3&0\\0&2&1&1&0\\1&2&2&2&0\end{pmatrix}=A\begin{pmatrix}1&1&-1&-1\\2&-1&2&-1\\-1&1&1&0\\0&1&1&1\end{pmatrix}(T,X)$$

$$\therefore\left(\begin{array}{cccc:ccccc}1&1&-1&-1&2&0&-2&1&1\\2&-1&-2&-1&1&1&1&3&0\\-1&1&1&0&0&2&1&1&0\\0&1&1&1&1&2&2&2&0\end{array}\right)\to\left(\begin{array}{cccc:ccccc}1&1&-1&-1&2&0&-2&1&1\\0&-3&4&1&-3&1&5&1&-2\\0&2&0&-1&2&2&-1&2&1\\0&1&1&1&1&2&2&2&0\end{array}\right)?$$

$$\to\left(\begin{array}{cccc:ccccc}1&0&-2&-2&1&-2&-4&-1&1\\0&1&1&1&1&2&2&2&0\\0&0&-2&-3&1&-2&-5&-2&1\\0&0&7&4&0&7&11&7&-2\\0&0&1&-5&0&1&-4&1&1\end{array}\right)\to\left(\begin{array}{cccc:ccccc}1&0&0&-12&1&0&-12&1&3\\0&1&0&6&1&1&6&1&-1\\0&0&1&-5&0&1&-4&1&1\\0&0&0&-13&0&0&-13&0&3\end{array}\right)$$

$$\rightarrow\left(\begin{array}{cccc:ccccc}1&0&0&0&1&0&0&1&3/13\\0&1&0&0&1&1&0&1&5/13\\0&0&1&0&0&1&1&1&-2/13\\0&0&0&0&0&0&1&0&-3/13\end{array}\right)$$

因此: 过渡矩阵 $T=\begin{pmatrix}1&0&0&1\\1&1&0&1\\0&1&1&1\\0&0&1&0\end{pmatrix}$

令 在$\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4$下的坐标为 $\left(\frac{5}{13},\frac{5}{13},-\frac{2}{13},-\frac{3}{13}\right)$

P269.9③ $\varepsilon_1=(1,1,1,1)\varepsilon_2=(1,1,-1,-1),\varepsilon_3=(1,-1,1,-1)\varepsilon_4=(1,-1,-1,1)$

$\eta_1=(1,1,0,1),\eta_2=(2,1,3,1),\eta_3=(1,1,0,0),\eta_4=(1,-1,-1,1)$

求 $\xi=(1,0,0,-1)$在$\eta_1,\eta_2,\eta_3,\eta_4$下的坐标

解 若 $(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)T=(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)$那么

$$T=\begin{pmatrix}1&1&1&1\\1&1&-1&-1\\1&-1&1&-1\\1&-1&-1&1\end{pmatrix}+\begin{pmatrix}1&2&1&0\\1&1&1&1\\0&3&0&-1\\1&1&0&-1\end{pmatrix}=\frac{1}{4}\begin{pmatrix}1&1&1&1\\1&1&-1&-1\\1&-1&1&-1\\1&-1&-1&1\end{pmatrix}\begin{pmatrix}1&2&1&0\\1&1&1&1\\0&3&0&-1\\1&1&0&-1\end{pmatrix}$$

$$=\frac{1}{4}\begin{pmatrix}3&-1&2&-1\\1&-1&2&3\\-1&3&0&-1\\1&-1&0&-1\end{pmatrix}\quad 而\xi=(\eta_1,\eta_2,\eta_3,\eta_4)y=(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)x$$

$$=(\eta_1,\eta_2,\eta_3,\eta_4)TY$$

$$\therefore Y=T^{-1}X\qquad X=A^{-1}\begin{pmatrix}1\\0\\0\\1\end{pmatrix}=\frac{1}{4}\begin{pmatrix}1&1&1&1\\1&1&-1&-1\\1&-1&1&-1\\1&-1&-1&1\end{pmatrix}=\frac{1}{2}\begin{pmatrix}1\\0\\0\\1\end{pmatrix}$$

不如直接解出

$$\xi=(\eta_1,\eta_2,\eta_3,\eta_4)y\quad\therefore\begin{pmatrix}1&2&0&1\\1&1&1&0\\0&3&-1&0\\1&1&-1&-1\end{pmatrix}\rightarrow\begin{pmatrix}1&2&1&0\\0&-1&0&1\\0&3&0&-1\\0&0&-1&-2\end{pmatrix}\begin{pmatrix}1\\-1\\0\\-1\end{pmatrix}$$

y

$$\begin{pmatrix}1&0&1&2\\0&1&0&-1\\0&0&0&2\\0&0&1&2\end{pmatrix}\begin{pmatrix}-1\\1\\-3\\1\end{pmatrix}\to\begin{pmatrix}1&0&0&0\\0&1&0&-1\\0&0&1&2\\0&0&0&2\end{pmatrix}\to\begin{pmatrix}-2\\1\\1\\-3\end{pmatrix}\to\begin{pmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{pmatrix}\begin{pmatrix}-2\\-1/2\\4\\-3/2\end{pmatrix}$$

故 $\xi=-2\eta_1-\frac{1}{2}\eta_2+4\eta_3-\frac{3}{2}\eta_4$ 在该基下坐标为 $\left(-2,-\frac{1}{2},4,-\frac{3}{2}\right)$

P269.10.设 $\xi=(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)x=(\eta_1,\eta_2,\eta_3,\eta_4)X$ 作 $A=\begin{pmatrix}2&0&5&6\\1&3&3&6\\-1&1&2&1\\1&0&1&3\end{pmatrix}$

$$\begin{pmatrix}1&0&5&6\\1&2&3&6\\-1&1&1&1\\1&0&1&2\end{pmatrix}\to\begin{pmatrix}1&0&1&2\\0&2&2&4\\0&1&2&3\\0&0&4&4\end{pmatrix}\to\begin{pmatrix}1&0&1&2\\0&1&1&2\\0&0&1&1\\0&0&4&4\end{pmatrix}\to\begin{pmatrix}1&0&0&1\\0&1&0&1\\0&0&1&1\\0&0&0&0\end{pmatrix}\quad\therefore$$

解 $x=k\begin{pmatrix}1\\1\\1\\-1\end{pmatrix}$

只要k≠0 即可，取k=1 即有 $\xi=\varepsilon_1+\varepsilon_2+\varepsilon_3-\varepsilon_4=(1,1,1,-1)$

P269.11， $V_1=R_R,V_2=R^+{}_R$ 规定 $B:R\to R^+,a\to e^a$ （自然对数）

则 B 是 $1-1$ 的和映上以 $\left(a\neq b\Rightarrow e^a\neq e^b,\text{正定}b\text{原为}\ln b\right)$

又 $\because\delta(a+b)=e^{a+b}=e^a\cdot e^b=e^a\oplus e^b=\delta(a)\oplus\delta(b)$

$\delta(ka)=e^{ka}=\left(e^a\right)^k=k\bullet e^a=k\bullet\delta(a)$

故 δ 就是同构，$R\cong R^+$ 其实任取一个数d(d>0,d≠)代替e均可：

$(p_{269})12$ 设 $V_1\subseteq V_2,V_1\leq V,V_2\leq V$，且 $\dim V_1=\dim V_2$

证明 $V_1=V_2$

只须证 $V_1\supseteq V_2$

证：设 $\dim V_1=\dim V_2=r$，且 $\alpha_1,\alpha_2,\cdots,\alpha_r$ 为 V_1 的个基任取 $\beta\in V_2$

$\alpha_1,\alpha_2,\cdots,\alpha_r\in V_2$ 且在 V_2 中线性无关.

因为 $\dim V_2=r$，故 V_2 中这 $r+1$ 个向量 $\beta,\alpha_1,\alpha_2,\cdots,\alpha_r$，线性相关，由临界定理.

$$\beta\leftarrow\alpha_1,\alpha_2,\cdots,\alpha_r\Rightarrow\beta\in V_1$$

即 $V_2 \subseteq V_1$中（得证）

$(P_{269,}13), C(A)=\left\{x \in p^{n\times n} \middle| AX = XA\right\} \subseteq P^{n\times n}$

1）$\because 0 \in C(A) \neq \phi$

$\forall X, Y \in C(A) \Rightarrow A(X+Y) = AX + AY = XA + YA = (X+Y)A$

$\Rightarrow A(kX) = k(AX) = k(XA) = X(kA)$

$\therefore x+y, kA \in C(A)$即C（A）⩽ $P^{n\times n}$

2）$\because \forall x \in p^{n\times n}$,有$XE = EX$,故$X \in C(E)$

$\therefore P^{n\times n} \subseteq C(E)$但$C(E) \subseteq P^{n\times n}$

$\therefore$当$A=E$时,$C(A)=C(E)=P^{n\times n}$

3）$\forall x = (x_{ij}) \in P^{n\times n}$ 由于 $A = \begin{pmatrix} 1 & & & \\ & 2 & & \\ & & \cdots & \\ & & & n \end{pmatrix}$

有X$\in C(A) \Leftrightarrow XA = AX$

$\Leftrightarrow XA$第i行j列元素，$jx_{ij} = AX$第i行j列元素ix_{ij},

$(\forall, ij)$

$\Leftrightarrow (\forall i, j)$，$xi_j(i-j)=0$

$\Leftrightarrow i \neq j$时$xi_j = 0$,若$i=j$,则$i=j$,则x_{ii}任意

$$\Leftrightarrow X = \begin{pmatrix} x_{11} & & & \\ & x_{22} & & \\ & & \cdots & \\ & & & x_{nn} \end{pmatrix} = \sum_{i=1}^{n} x_{ii}E_{ii}$$

$E_{11,}E_{22}, \cdots, E_{nn}$线性无关

此时C（A）是全体对角矩阵，E_{11}，E_{22}，⋯，E_{nn}是它的一个基，故 dimC(A)=n

P270.14 设 $x = \begin{pmatrix} a & b & c \\ d & e & f \\ q & h & i \end{pmatrix}$ $Ax = \begin{pmatrix} a & b & c \\ b & e & f \\ 3a+d+2g & 3b+e+2h & 3c+f+2i \end{pmatrix}$

$XA = \begin{pmatrix} a+3c & b+c & 2c \\ d+3f & e+f & 2f \\ q+3i & h+i & 2i \end{pmatrix}$ $\therefore AX = XA \Rightarrow a = a+3c \Rightarrow c=0, d = d+3f \Rightarrow f=0$

且 $\begin{cases} 3a+d+2g = g+3i \\ 3b+e+2h = h+i \\ 2i = 2i \end{cases}$ $\therefore \begin{cases} 3a+d+q = 3i \\ 3b-e+h = i \\ i, a, d, b, e\text{任意} \end{cases}$

$\therefore$ 依次取 $(a,b,d,e,i)=\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4,\varepsilon_5$ 得基元素

$$\begin{pmatrix}1&0&0\\0&0&0\\-3&0&0\end{pmatrix}\begin{pmatrix}0&1&0\\0&0&0\\0&-3&0\end{pmatrix}\begin{pmatrix}0&0&0\\1&0&0\\-1&0&0\end{pmatrix}\begin{pmatrix}0&0&0\\0&1&0\\0&-1&0\end{pmatrix}\begin{pmatrix}0&0&0\\0&0&0\\3&1&1\end{pmatrix}$$

dimC(A)=5

p270.15 $c_1c_3\neq 0,\ c_1d+c_2\beta+c_3r=0\Rightarrow\ \alpha=-\frac{c_2}{c_1}\beta-\frac{c_3}{c_1}r,\ r=\frac{c_1}{c_3}\alpha-\frac{c_2}{c_3}\beta$

$\therefore \alpha.\beta\overrightarrow{\leftarrow}\beta.r\Rightarrow L(\alpha.\beta)=L(\beta.r)$

P270.16① $\begin{pmatrix}\alpha_1\\\alpha_2\\\alpha_3\\\alpha_4\end{pmatrix}=\begin{pmatrix}2&1&3&1\\1&2&0&1\\-1&1&-3&0\\1&1&1&1\end{pmatrix}\Rightarrow\begin{pmatrix}1&1&1&-1\\0&1&-1&0\\0&2&-2&1\\0&-1&1&-1\end{pmatrix}\rightarrow\begin{pmatrix}1&1&1&1\\0&1&-1&0\\0&0&0&1\\0&0&0&-1\end{pmatrix}$

$\rightarrow\begin{pmatrix}1&1&1&1\\0&1&-1&0\\0&0&0&1\\0&0&0&0\end{pmatrix}\therefore \alpha_4,\alpha_2,\alpha_3$ 线性无关

$(\alpha_1,\alpha_2,\alpha_3,\alpha_4)=3$ 故基为 $\alpha_2,\alpha_3,\alpha_4,$

P270.16② $\begin{pmatrix}\alpha_1\\\alpha_2\\\alpha_3\\\alpha_4\end{pmatrix}=\begin{pmatrix}2&1&3&-1\\-1&1&-3&1\\4&5&3&-1\\1&5&-3&1\end{pmatrix}\rightarrow\begin{pmatrix}2&1&3&-1\\1&2&0&0\\2&4&0&0\\3&5&0&0\end{pmatrix}\rightarrow\begin{pmatrix}2&1&3&-1\\1&2&0&0\\0&0&0&0\\0&0&0&0\end{pmatrix}$

$\therefore$ 秩 $(\alpha_1,\alpha_2,\alpha_3\alpha_4)=2,\alpha_1,\alpha_2$ 是一个极大无关组

$\therefore \dim L(\alpha_1,\alpha_2,\alpha_3,\alpha_4)=2,\alpha_1,\alpha_2$ 是它的一个基

P270.17 $\begin{pmatrix}3&2&-5&4\\3&-1&3&-3\\3&5&-13&11\end{pmatrix}\rightarrow\begin{pmatrix}3&2&-5&4\\0&-3&8&-7\\0&3&-8&7\end{pmatrix}\rightarrow\begin{pmatrix}1&2/3&-5/3&4/3\\0&1&-8/3&7/3\\0&0&0&0\end{pmatrix}$

$\rightarrow\begin{pmatrix}1&0&1/9&-2/9\\0&1&-8/3&7/3\\0&0&0&0\end{pmatrix}$

系数矩阵为A，秩（A）=2 基础解系含 4-2=2 个向量，可为 $\begin{pmatrix}-1\\24\\9\\0\end{pmatrix}\begin{pmatrix}2\\-21\\0\\9\end{pmatrix}$

∴解空间的维数为 2，基底一个是

$$(-1,24,9,0),(2,21,0,9)$$

（P270，18，①）解设 $V_1=L(\alpha_1,\alpha_2)V_2=L(\beta_1,\beta_2)$

若设 $r=x_1\alpha_1+x_2\alpha_2=x_3\beta_1+x_4\beta_2$ 即 $r\in V_1\cap V_2$

则 $\begin{cases}x_1-x_2-2x_3-x_4=0\\2x_1+x_2+x_3+x_4=0\\x_1+x_2-3x_4=0\\x_2-x_3-7x_4=0\end{cases}$ $\begin{pmatrix}1&-1&-2&-1\\2&1&1&1\\1&1&0&-3\\0&1&-1&-7\end{pmatrix}\to\begin{pmatrix}1&-1&-2&-1\\0&3&5&3\\0&2&2&-2\\0&1&-1&-7\end{pmatrix}$

$$\to\begin{pmatrix}1&0&-1&-2\\0&1&1&-1\\0&0&2&6\\0&0&-2&-6\end{pmatrix}\to\begin{pmatrix}1&0&0&1\\0&1&0&-4\\0&0&1&3\\0&0&0&0\end{pmatrix}$$

有非零解如 $\begin{pmatrix}x_1\\x_2\\x_3\\x_4\end{pmatrix}=\begin{pmatrix}-1\\4\\-3\\1\end{pmatrix}$ 即

$\because$ 秩$(\alpha_1,\alpha_2,\beta_1,\beta_2)=3$所以$\dim(V_1\cap V_2)=2+2-3=1$维

它的一个基是 $r=(-5,2,3,4)$

（P270，18，②）解：设V_1=L（α_1,α_2），$V_2=L(\beta_1,\beta_2)$则由

$$\begin{pmatrix}1&1&0&0\\1&0&1&1\\0&0&1&1\\0&1&1&0\end{pmatrix}\to\begin{pmatrix}1&1&0&0\\0&-1&1&1\\0&0&1&1\\0&1&1&0\end{pmatrix}\to\begin{pmatrix}1&1&0&0\\0&1&-1&-1\\0&0&1&1\\0&0&2&1\end{pmatrix}\to\begin{pmatrix}1&1&0&0\\0&1&-1&-1\\0&0&1&1\\0&0&0&-1\end{pmatrix}$$

由此秩$(\alpha_1,\alpha_2,\beta_1,\beta_2)=4\therefore\dim(V_1+V_2)=\dim L(\alpha_1,\alpha_2,\beta_1,\beta_2,)=4$而

$\dim V_1=\dim V_2=2$，所以$\dim(V_1\cap V_2)=2+2-4=0$

此时$V_1\cap V_2$没有基.

（P270，18，③）$解:设V_1=L(\alpha_1,\alpha_2,\alpha_3),V_2=L(\beta_1,\beta_2)$

由 $\begin{pmatrix}\alpha_1\\\alpha_2\\\alpha_3\end{pmatrix}=\begin{pmatrix}1&+2&-1&-2\\3&1&1&1\\-1&0&1&-1\\&&&\end{pmatrix}\Rightarrow\begin{pmatrix}1&2&-1&-2\\0&1&4&-2\\0&2&0&-3\\&&&\end{pmatrix}$ 秩为3 $\therefore\dim V_1=3$ 显有$\dim V_2=2$

设$r=x_1\alpha_1+x_2\alpha_2+x_3\alpha_3=x_4\beta_2\in V_1\cap V_2$则得

$$\begin{cases} x_1+3x_2-x_3-2x_4+x_5=0 \\ 2x_1+x_2-5x_4-2x_5=0 \\ -x_1+x_2+x_3+6x_4+7x_5=0 \\ -2x_1+x_2-x_3+5x_4-3x_5=0 \end{cases}$$

$$\begin{pmatrix} 1 & 3 & -1 & 1 \\ 2 & 1 & 0 & -2 \\ -1 & 1 & 1 & 7 \\ -2 & 1 & 1 & -3 \end{pmatrix} \to \begin{pmatrix} 1 & 3 & -1 & 1 \\ 0 & -5 & 2 & -4 \\ 0 & 4 & 0 & 8 \\ 0 & 7 & -3 & -1 \end{pmatrix} \to \begin{pmatrix} 1 & 0 & 5 & 13 \\ 0 & -1 & 2 & 4 \\ 0 & 0 & 2 & 6 \\ 0 & 0 & 11 & 27 \end{pmatrix} \to \begin{pmatrix} 1 & 0 & 0 & -2 \\ 0 & -1 & 0 & -2 \\ 0 & 0 & 1 & 3 \\ 0 & 0 & 0 & -6 \end{pmatrix}$$

$\to \begin{pmatrix} 1 & 0 & 0 & 00 \\ 0 & 1 & 0 & 00 \\ 0 & 0 & 1 & 00 \\ 0 & 0 & 0 & 11 \end{pmatrix}$ 秩为 3：即秩$\left(\alpha'_1,\alpha'_2,\alpha'_3,\beta'_1,\beta'_2,\right)=4$

$\therefore \dim(V_1+V_2)=4$故$\dim(V_1\cap V_2)=5-4=1$

取方程组一个非零解$(x_1,x_2,x_3,x_4,x_5)=(3,-1,-2,1,0)$

即$\beta_1=r=3\alpha_1-\alpha_2-2\alpha_3,\in V_1\cap V_2$是一个所求的基

P270.19 $x_1,+x_2+\cdots+x_n=0$的空间V_1 $\dim V_1=n$一秩$(1,1,1,\cdots,1)=n-1$

$x_1=x_2=\cdots=x_n=0$的解空间V_2 , $A=\begin{pmatrix} 1-1 & & \\ & 1-1 & \\ & & 1-1 \end{pmatrix}$

$x_1=x_2=\cdots=x_n$的解空间V_2

$\dim V_2=n$一秩$(A)=n-(n-1)=1$

若 $\xi=(\alpha_1,\alpha_2,\cdots,\alpha_n)\in V_1\cap V_2$, 则$\left.\begin{matrix}\Rightarrow \alpha_1=\alpha_2=\cdot=\alpha_n\overset{\Delta}{=}\alpha \\ \Rightarrow \alpha_1,\alpha_2+\cdot+\alpha_n(=n\alpha)=0\end{matrix}\right\}\Rightarrow\alpha=0$

$\therefore \xi=(\alpha,\alpha,\cdots,\alpha)=0$即由定理8推论$V_1+V_2$是直和

$\because \dim(V_1\oplus V_2)=(n-1)+1=n$ 是$V_1+V_2\subseteq P^n$,

$\dim(V_1\oplus V_2)=\dim p^n$(由12题6.88.8.3)$P^n=V_1\oplus V_2$

P271，20，设$V=V_1\oplus V_2, V_1=V_{11}\oplus V_{12}$那么$V=V_{11}\oplus V_{12}\oplus V_2$

证一：设$0=\alpha_{11}+\alpha_{12}+\alpha_2 \because V=V_1\oplus V_2$

$\therefore \alpha_2=0, \alpha_{11}+\alpha_{12}\in V_1$也为0 即

$O=\alpha_{11}+\alpha_{12}为V_{11}\oplus V_{12}的$直和分解或故

$\alpha_{11}=0,\alpha_{12}=0,所以0有唯一分解式0=0_{11}+0_{12}+0_{2}$

$\therefore V=V_{11}\oplus V_{12}\oplus V_{2}$

证二：$\dim V=\dim V_1+\dim V_2=\left(\dim V_{11}+\dim V_{12}\right)+\dim V_2$

证毕

P271.21 $\because V=L\left(\alpha_1,\alpha_2,\cdots,\alpha_m\right)\quad 作W_i=L\left(\alpha_i\right)$

$若\forall\beta\in V\quad \beta=\sum_{i=1}^{n}\beta_i=\sum_{i=1}^{n}r_i\qquad \beta_iV_i\in W_i\quad 可设\beta=b_i\alpha_i,y_i=-\frac{c_2}{c_3}\beta$

$\Rightarrow 0=\Sigma\left(\beta_i-r_i\right)=\Sigma\left(b_i-c_i\right)d_i,无关性\Rightarrow b_i-c_i=0\therefore b_i=c_i$

因此 $\beta_i=r_i\quad \therefore\beta的分解式唯一,\quad \therefore V=W_1\oplus W_2\oplus\cdots\oplus W_n$

P271.22$\because$ $W_i=\sum_{j=1}^{i-1}V_j\subseteq\sum_{j\neq i}^{s}V_j=V_i$ 故若 $\sum_{i=1}^{s}V_i$ 为直和则 $r_i\bigcap V_i=\{0\}$

$\therefore V_i\bigcap W_i=\{0\}$从而必要性显然.

反过来证充分性

若 $\sum_{i=1}^{s}V_i不是直和,有\alpha_1,\alpha_2,\cdots,\alpha_s,\alpha_i\in V_i不全为0,且0=\alpha_1+\alpha_2+\ldots+\alpha_s$

$\alpha_k为\alpha_s,\alpha_{s-1},\cdots,\alpha_2,\alpha_1$中第一个不为 0 的向量故

$$0\neq\alpha_k=\left(-\alpha_1\right)+(-\alpha_2)+\ldots+\left(-\alpha_{k-1}\right)\subseteq\sum_{j=1}^{k-1}V_j=W_K$$

显然若k=1$\Rightarrow\alpha_1\neq0,\alpha_2=\cdots=\alpha_S=0,而0-\alpha_1+0+0+\cdot+0矛盾\therefore k\geq2$

又$\alpha_k\in V_k从而V_k\bigcap W_k\geq\neq\{0\}$与已知矛盾，故

$$\sum_{i=1}^{s}V_i=V_1\oplus V_2\oplus\cdots\oplus V_S$$

P271.23②当平面经过原点是线性子空间，不经过原点则不是

$\because 若0\in平面\qquad \alpha\in平面$

则$k\alpha\left(k\neq1\right)\notin平面$

23②L_1+L_2生成直线$\left(当L_1=L_2\right)$

生成直线$\left(当L_1\neq L_2\right)$

$L_1+L_2+L_3$生成直线$\left(当L_1=L_2+L_3\right)$

生成直线$\left(当L_1,L_2,L_3,共面\right)$

生成空间$R^3$$\left(当L_1,L_2,L_3不共面\right)$

23②当然不一定有　如右图

$V+V$ 不x平面　y为平面中线

$y\subseteq x$

但$y\bigcap V=0,Y\bigcap V=0,\therefore y\neq\left(y\bigcap V\right)+\left(y\bigcap V\right)=0$

P_{271}补 1①因为 $f_i\left(x\right)=\dfrac{f\left(x\right)}{x-a_i}$　　$f\left(x\right)=\left(x-a_1\right)(x-a_2).......\left(x-a_n\right)$

$f_i\left(a_k\right)=0\left(k\neq i\right)$ 或 $f_i\left(a_i\right)=\prod\limits_{(j\neq i)}\left(a_i-a_j\right)$

如果n=1,则 $f_1(x)=1$ 显然$(\neq 0)$线性无关

如果n≥2，而 $f_1(x),f_2(x),\cdots,f_n(x)$ 线性相关,则不妨设 $f_1(x)=\sum\limits_{i=2} k_i f_i(x)$

但是在 $x=a_1$ 处值,右边恒为 0,左边为 $f_1(a_1)=\prod\limits_{j=2}^{n}(a_1-a_j)\neq 0$

矛盾$\therefore$ $f_1(x),f_2(x),...,f_n(x)$ 线性无关,而dimP[X]=n

以及单个 $f_i(x),次数\leq n-1,\therefore f_i(x)\in p[x]_n.故诸f_i(x)形成基$

P_{271}补 1② $x^n=1的单数根为\omega\ ,\omega^2,\omega^3,...,\omega^n=1,(\omega本原的)\ a_i=\omega^i$

$$\therefore\ f_i(x)=\frac{f(x)}{x-a_i}=\frac{x^{n-1}}{x-w^i}=\frac{\omega^u-(\omega^{\,i})^u}{x-\omega^{\,i}}=x^{n-1}+\omega^{\,i}x^{u-2}+\omega^{\,i}x^{u-3}+...+\omega^{(n-1)i}$$

$$(f_1(x),f_2(x),...,f_n(x))=(1,x,x^2,,x^{n-1})\begin{pmatrix}1&1&...&1&1\\\omega&\omega^2&...&\omega^{n-1}&1\\\omega^2&\omega^4&...&\omega^{2(n-1)}&1\\...&...&...&...&...\\\omega^{n-1}&\omega^{2(n-1)}&...&\omega^{(n-1)^2}&1\end{pmatrix}$$

$$\therefore T=\begin{pmatrix} 1 & 1 & \dots & 1 & 1 \\ \omega & \omega^2 & \dots & \omega^{n-1} & 1 \\ \omega^2 & \omega^4 & \dots & \omega^{2(n-1)} & 1 \\ \dots & \dots & \dots & \dots & \dots \\ \omega^{n-1} & \omega^{2(n-1)} & \dots & \omega^{(n-1)^2} & 1 \end{pmatrix}$$

（P271 补 2）因 $\alpha_1,\alpha_2,\cdots,\alpha_n$ 线性无关，设秩 $(A)=r,\exists, p,Q$ 可逆使

$$A=P\begin{pmatrix} E_r & 0 \\ 0 & 0 \end{pmatrix}_{n\times s} Q$$

所以 $(\beta_1,\beta_2,\cdots,\beta_s)=(\alpha_1,\alpha_2,\cdots,\alpha_n)A$

$$=(\alpha_1,\alpha_2,\cdots,\alpha_n)P\begin{pmatrix} E_r & 0 \\ 0 & 0 \end{pmatrix}Q=(r_1,r_2,\cdots,r_n)\begin{pmatrix} E_r & 0 \\ 0 & 0 \end{pmatrix}Q=(r_1,r_2,\cdots,r_n)\begin{pmatrix} E_r & 0 \\ 0 & 0 \end{pmatrix}Q$$

$=(r_1,r_2,...,r_r,0,...,0)$

$\therefore \beta_1,\beta_2,\cdots,\beta_S \leftarrow r_1,r_2,\cdots,r_r$ 但Q可逆 $(r_1,\cdots,r_r,0,\cdots,0)=(\beta_1,\cdots,\beta_s)Q^{-1}$

$\therefore r_1,r_2,\cdots,r_r \leftarrow \beta_1,\beta_2,\cdots,\beta_s$ 由定理了

$$\dim(L(\beta_1,\beta_2,\cdots,\beta_s))=dim(L(r_1,r_2,\cdots,r_r))=秩(r_1,r_2,\cdots,r_r)=r=秩(A)$$

P271 补 3，设 $f(x_1,x_2,\cdots,x_m)=x'AX$

由 $秩(f)=n, f$ 的符号差为S，那么f的摂性指数 $p=\frac{n+s}{2}$

$$f的负惯性指数 q=\frac{1}{2}(n-s)$$

非退化线性替换，使

$$f(x_1\cdots x_n)=g(y_1\cdots y_n)=y^2{}_1+\cdots+y_p{}^2-y_{m+1}{}^2-\cdots-y^2{}_n$$

作 n 维向量

$$y_1=\begin{pmatrix}1\\0\\0\\1\\0\\0\end{pmatrix}=\varepsilon_1+\varepsilon_{p+1},y_2=\begin{pmatrix}0\\1\\0\\0\\1\\0\end{pmatrix}=\varepsilon_2+\varepsilon_{p+2},\cdots,y_q=\varepsilon_q+\varepsilon_{p+q}=\varepsilon_q+\varepsilon_n$$

那么 $g(y_1,\cdots,\ y_n)$ 在y_i处的值为 0 且，若

$$y_o=b_1y_1+b_2y_2+\cdots+b_qy_q$$

则 $g(y_1,\cdots,y_n)$ 在y_o的值为 $b_1{}^2+b_2{}^2+\cdots+b_q{}^2-b_1{}^2-b_q{}^2=0$

于是 $V_2=L(y_1,y_2,\cdots y_q)$ 及 $V_1=L(cy_1,cy_2,\cdots,cy_q)$

$\therefore f$在V_1中任意处 $\sum_{i=1}^{a}q_i(cy_i)$ 的值，等于q在 $\sum_{i=1}^{q}a_2y_i$ 的值为 0

$\because y_1,y_2,\cdots,y_q$ 线性无关，$\therefore x_1=cy_1,x_2=cy_2,\cdots x_t=cy_q$ 线性无关

$\therefore \dim V_1=q=\frac{1}{2}(n-s)=\frac{1}{2}(n-/s/)$

b^o如果 $s<0$ 则 $p<q$ 作 $x=cy,\ f=g(y_1,\cdots,y_n)$ 为规范形

这对可取 $y_1,y_2,\cdots,y_p$ 生成 V_2 且 V_2 要化g

同时作 $V_1=g(x_1,x_2,\cdots,x_p)=L(y_1,y_2cy_p)$

$(同a^o)V_1即使得f\ /V_1=0且$

$$\dim V_1=P=\frac{1}{2}(n+s)=\frac{1}{2}(n-/s/)$$

$(P271补4)$证法一：　　$\because V_1\neq V,V_2\neq V$

故若$V_1\subseteq V_2$则取一$\alpha\notin V_2$(α必存在)即可

若$V_1\supseteq V_2$则任取一$\alpha\notin V_1$(α也存在)即可

若$V_1\notin V_2,V_2\notin V_1$则可取$\alpha\in V_1,\alpha\notin V_2$和$\beta\in V_2,\beta\notin V_1$

$\because \alpha+\beta\in V_2\Rightarrow\beta\in V_1$矛盾,$\alpha+\beta\in V_2$也矛盾$\therefore\alpha+\beta\notin V_1,\notin V_2$即为所求.

证法 2：若$V_1\subseteq V_2$或$V_2\subseteq V_1$,同上显然

当$V_1\subseteq V_2,V_2\not\subseteq V_1$时,取$\alpha\notin V_1,\beta\in V_1,\beta\in V_2$,考虑一切的$\alpha+k\beta$ 如右图

$\{\alpha+k\beta\}$理解为V_1的平行体.

断言(a)若有$\alpha\in P,\alpha+k\beta\in V_1$ (b)至多存在一个k，使$\alpha+k\beta\in V_2$

证（a）有 $k\in p,\alpha+k\beta\in V_1\because\beta\in V_1\Rightarrow\alpha=(\alpha+k\beta)-k.\beta\in V_1$,矛盾！

（b）若有 $k_1\neq k_2\in p$使$\alpha+k_1\beta\in V_2,\alpha+K_2\beta\in V_2$则,$k_1\beta-k_2\beta\in V_2$

$$\Rightarrow (k_1-k_2)\beta \in V_2 \Rightarrow \beta \in V_2$$ 矛盾！

故若 $k_o \in p\alpha + k_o\beta \notin V_2$, 则 $\alpha + k_o\beta$ 即为所求，$\notin V_1, \notin V_2$,

若 $\alpha + k_o\beta \in V_2$ 则任取 $k_1 \neq k_o$ 有 $\alpha + k_1\beta \notin V_1, \notin V_2$ 即为所求

证法二虽然思想复杂，却可以把问题做大

（P272）补 5

$s=1$ 虽然 $(\because V_1$ 非平凡, $\therefore V_1 \neq V)$

$s=2$ 命题已证，即第 4 题设S=k时命题成交，考虑s=k+1 时，$V_1, V_2, \cdots V_k, V_{k+1}$ 皆非平凡了空间对于 $V_1, V_2, \cdots, V_k$ 任取 $\alpha \notin V_{k+1}$ $(\because V_{K+1} \neq V)$ 考虑一切 $\alpha + k\beta$

同样（类似 4 题证法 $(P_6, 92, 12, 3)$），$\forall k \in p, \alpha + k\beta \in V_{k+1}$ 对每个 V_i $(i = 1.2 \cdots k)$ 至多只须一个使，$\alpha + k_i\beta \in V_i$

取 r_o 为不同于 $r_1, r_2, \cdots, r_k, 1$ 的任一数即

$$t_o \in p - \{t_1, t_2, \cdots, V_K, V_{k+1}\}$$

那么 $l_o \notin V_1, V_2, \cdots, V_K, V_{k+1}$ $\therefore \alpha + t_o\beta$ 即为所求

第七章 线性变换习题解答

P320 1.① 不是 当 $\alpha \neq 0$ 时，$\mathrm{A}0 = 0 + \alpha = \alpha \neq 0$ 不是线性变性

当 $\alpha = 0$ 时，$\mathrm{A}\xi = \xi + 0 = \xi$，所以 $\mathrm{A} = \mathrm{E}$ 是线性变换

1．②$\mathbf{A}\,\xi = \alpha$.

α固定(1)若$\alpha = 0$,则A是零变换.

(2)若$\alpha \neq 0$,则$\mathrm{A}0 = \alpha \neq 0$,与基本性质$1^o$矛盾不是线性变换.

1．③（不是）含 $\alpha = (1,0,0)$，则 $\mathrm{A}\alpha = \alpha = (1,0,0)$

$\therefore \mathrm{A}(2\alpha) = \mathrm{A}(2,0,0) = (4,0,0) \neq (2,0,0) = 2\alpha$

$\therefore$ 不是线性变换

1．④$\mathbf{A}\left(x_1, x_2, x_3\right) = \left(2x_1 - x_2, x_2 + x_3, x_1\right)$

取 $\alpha = \left(x_1, x_2, x_3\right)$

$$\therefore \mathrm{A}\alpha = \mathrm{A}\left(x_1 x_2 x_3\right) = \left(x_1 x_2 x_3\right)\begin{pmatrix} 2 & 0 & 1 \\ -1 & 1 & 0 \\ 0 & 1 & 0 \end{pmatrix} = \alpha A.$$

$\forall \alpha, \beta \in p^3 : k \in p \qquad \beta = \left(y_1, y_2, y_3\right)$

$\therefore \mathrm{A}\left(\alpha + \beta\right) = \left(\alpha + \beta\right) A = \alpha A + \beta A = \mathrm{A}\alpha + \mathrm{A}\beta$

$\mathrm{A}\left(k\alpha\right) = \left(k\alpha\right) A = k\left(\alpha A\right) = k\mathrm{A}\left(\alpha\right)$

$\therefore \mathrm{A}$ 是一个线性变换

1.⑤（是）$\forall$ $f(x), g(x) \in P[x]$，令 $h(x) = f(x) + g(x)$， $h(x) = kf(x)$ 则

$\mathrm{A}h(x) = h(x+1) = f(x+1) + g(x+1) = \mathrm{A}f(x) + \mathrm{A}g(x)$

$\mathrm{A}(h(x)) = \mathrm{A}(kf(x)) = h(x+1) = kf(x+1) = k\mathrm{A}f(x)$

因此 A 是一个线性变换

P321 1.⑥ $\forall f \in P[x], x_0 \in P$固定,$\mathrm{A}f\left(x\right) = f\left(x_0\right).$

解 $\forall f(x), g(x) \in P[x], k \in P$, $h(x)=f(x)+g(x)$

$l(x)=kf(x)$

$$\therefore \mathrm{A}\left(f(x)+g(x)\right)=\mathrm{A}h(x)=h(x_0)=f(x_0)+g(x_0)$$
$$=\mathrm{A}\left(f(x)\right)+\mathrm{A}\left(g(x)\right)$$

$$\therefore \mathrm{A}\left(kf(x)\right)=\mathrm{A}\ell(x)=\ell(x_0)=kf(x_0)=k\mathrm{A}\left(f(x)\right).$$

因此这里的投射 A 是一个线性变换.

1.⑦（不是） $\mathrm{A}\xi=\xi$, 因为 $P=\mathrm{C}, \xi\in\mathrm{C}$

则 $\overline{\xi}=\mathrm{A}\xi=\mathrm{A}(\xi\cdot 1)=\xi\cdot\mathrm{A}(1)=\xi\overline{1}=\xi$

但**C**中任意复数，一般 $\overline{\xi}\neq\xi$，故 / A不是线性变换

P321 .1.⑧， $\mathrm{P}^{m\times n}$中， $\forall X\in \mathrm{P}^{m\times n}$. 则 $\mathrm{A}\left(X\right)=B\times C\left(B,C\text{固定矩阵}\right)$. 由矩阵运算性质

$$\mathrm{A}\left(X+Y\right)=B\left(X+Y\right)C=\left(BX+BY\right)C=BXC+BYC$$

$$=\mathrm{AX}+\mathrm{A}Y.$$

$$\mathrm{A}\left(kX\right)=B\left(kX\right)C=k\left(BXC\right)=k\mathrm{AX}.$$

故 A 是一个线性变换.

P321 .2.解 $(x、y、z)$ 为空间的一点M

那么， $\mathrm{A}(x,y,z)=(x,-z,y)$

$\mathrm{B}(x,y,z)=(z,y,-x)$

$\mathrm{C}(x,y,z)=(-y,x,z)$

因此： $AB(x,y,z)\to(z,y,-x)\to(z,x,y)$

$BA(x,y,z)\to(x,-z,y)\to(y,-z,-x)\therefore AB\neq BA$

$A^2:(x,y,z)\to(x,-z,y)\to(x,-y,-z)$

$B^2:(x,y,z)\to(z,y,-x)\to(-x,y,-z)$

$C^2:(x,y,z)\to(-y,x,z)\to(-x,-y,z)$

$\therefore A^4:(x,y,z)\xrightarrow{A^2}(x,-y,-z)\to(x,y,z)$ $\qquad A^4=E$

$B^4:(x,y,z)\xrightarrow{B^2}(-x,y,-z)\to(x,y,z)$ $\qquad B^4=E$

$C^4:(x,y,z)\xrightarrow{C^2}(-y,x,z)\to(-x,-y,z)$ $\qquad C^4=E$

$A^2B^2:(x,y,z)\to(-x,y,-z)\to(-x,-y,z)$

$B^2A^2:(x,y,z)\to(x,-y,-z)\to(-x,-y,z)$ $\qquad \therefore A^2B^2=B^2A^2$

$(AB)^2:(x,y,z)\to(z,x,y)\to(y,z,x)$ $\qquad \therefore A^2B^2\neq(BA)^2$

P321， 3解： $\because Af(x)=f'(x), Bf(x)=xf(x)$， 故 $f(x)\in P[x]$

$(AB-BA)f(x)=A(Bf(x))-B(Af(x))=A(xf(x))-B(f'(x))$

$=xf'(x)+f(x)-xf'(x)=f(x)=Ef(x)$ $\qquad AB-BA=E$

$P_{321.}4, AB-BA=E.$证明$A^kB-BA^k=kA^{k-1}\left(k\geq1\right)$

（第3习题里给出了这样的 A,B 是存在的）

证：当k=1时（已知）

设$k\leq r$成立,当$k=r+1$时

$A^{r+1}B-BA^{r+1}=A^{r+1}B-A^rBA+A^rBA-BA^{r+1}$

$=A^r\left(AB-BA\right)+\left(A^rB-BA^r\right)A$

$=A^r\cdot E+\left(rA^{r-1}\right)A=A^r+rA^r=\left(r+1\right)A^r.$ 也成立

故对一切自然数 $k: \mathrm{A}^k\mathrm{B}-\mathrm{B}\mathrm{A}^k = k\mathrm{A}^{k-1}$

例进一步 $\mathrm{AB}-\mathrm{BA}=\mathrm{E}, f(x)\in \mathrm{P}[x]$, 计算

$$f(\mathrm{A})\mathrm{B}-\mathrm{B}f(\mathrm{A})=?$$

解：设 $f(x)=a_o+a_1x+\cdots+a_mx_m=\sum_{k=0}^{m}a_kx^k$

$$\therefore f(\mathrm{A})\mathrm{B}-\mathrm{B}f(\mathrm{A})=\left(\sum_{k=0}^{m}a_k\mathrm{A}^k\right)\mathrm{B}-\mathrm{B}\left(\sum_{k=0}^{m}a_k\mathrm{A}^k\right)$$

$$=\left(a_o\mathrm{A}^o\right)\mathrm{B}-\mathrm{B}\left(a_o\mathrm{A}^o\right)+\left(\sum_{k=1}^{m}a_k\mathrm{A}^k\right)\mathrm{B}-\mathrm{B}\left(\sum_{k=1}^{m}a_k\mathrm{A}^k\right)$$
$$=a_o\mathrm{B}-a_o\mathrm{B}+\sum_{k=1}^{m}\left(a_k\mathrm{A}^k\mathrm{B}-a_k\mathrm{B}\mathrm{A}^k\right)$$
$$=\sum_{k=1}^{m}a_k\left(\mathrm{A}^k\mathrm{B}-\mathrm{B}\mathrm{A}^k\right)=\sum_{k=1}^{m}a_k\cdot k\mathrm{A}^{k-1}$$
$$=a_1\mathrm{E}+2a_2\mathrm{A}+3a_3\mathrm{A}^2+\cdots+ma_m\mathrm{A}^{m-1}$$

$$\left(=?=f'(x)\ \Big|_{\mathrm{A}\to\mathrm{X}}\right)=f'(\mathrm{A}).$$

P321.5 可逆换是**1-1**对应

证：设**A**的逆变换$\mathbf{A^{-1}}$，$\forall\alpha\neq\beta\in V$, 若$\mathrm{A}^{-1}(\alpha)=\mathrm{A}^{-1}(\beta)$则

$\alpha=\mathrm{E}(\alpha)=\mathrm{A}\left(\mathrm{A}^{-1}(\alpha)\right)=\mathrm{A}\left(\mathrm{A}^{-1}(\beta)\right)=\left(\mathrm{A}\mathrm{A}^{-1}\right)\beta=\mathrm{E}\beta=\beta.$ 矛盾,故象不同$\mathbf{A^{-1}}$是单射（**1-1**的）

此外若有 $\alpha\in V,\exists\mathrm{A}\alpha=\beta$, 那使$\mathrm{A}^{-1}(\beta)=\mathrm{A}^{-1}(\mathrm{A}\alpha)=\alpha.$

$\therefore \mathrm{A}^{-1}$ 是满射（映上的）$\therefore$ A^{-1}是1-1对应

P321 6 $\mathrm{A}\in L(V)$ "$\Rightarrow$"

若**A**可逆，可 $\exists\mathrm{B}\in L(V)$, $\mathrm{BA}=\mathrm{AB}=\mathrm{E}$

对于 $\sum_{i=1}^{n}k_i\mathrm{A}\varepsilon_i=0\Rightarrow 0=\mathrm{B}(\sum_{i=1}^{n}k_i\mathrm{A}\varepsilon_i)=\sum_{i=1}^{n}k_i(\mathrm{BA}\varepsilon_i)=\sum_{i=1}^{n}k_i\varepsilon_i$

$k_i=0,(i=1,2,\cdots n)$ 故 $\mathrm{A}\varepsilon_1,\mathrm{A}\varepsilon_2,\cdots,\mathrm{A}\varepsilon_n$ 线性无关

"$\Leftarrow$" 若 $(\mathrm{A}\varepsilon_1,\mathrm{A}\varepsilon_2,\cdots,\mathrm{A}\varepsilon_n)=(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n)\mathbf{A}$，则A是一个基与基之间的过渡矩阵，**A**可逆，由定理2④，A 一个可逆变换。

$\mathrm{P}_{321.7}$ ① $\mathrm{A}(x_1,x_2,x_3)=(2x_1-2x_2,x_2+x_3,x_1)$ 在标准基下的矩阵

$$\mathrm{A}\varepsilon_1=(2,0,1)=(\varepsilon_1\varepsilon_2\varepsilon_3)\begin{pmatrix}2\\0\\1\end{pmatrix}\qquad \mathrm{A}\varepsilon_2=(-1,1,0)=(\varepsilon_1\varepsilon_2\varepsilon_3)\begin{pmatrix}-1\\1\\0\end{pmatrix}$$

$$\mathrm{A}\varepsilon_3=(0,1,0)=(\varepsilon_1\varepsilon_2\varepsilon_3)\begin{pmatrix}0\\1\\0\end{pmatrix}$$

$$\therefore \mathrm{A}(\varepsilon_1\varepsilon_2\varepsilon_3)=(\varepsilon_1\varepsilon_2\varepsilon_3)\begin{pmatrix}2&-1&0\\0&1&1\\1&0&0\end{pmatrix}$$

7、②（1）$\mathrm{A}\varepsilon_1=\frac{1}{2}\varepsilon_1+\frac{1}{2}\varepsilon_2$

$$\mathrm{A}\varepsilon_2=\frac{1}{2}\varepsilon_1+\frac{1}{2}\varepsilon_2$$

$$\therefore \mathrm{A}(\varepsilon_1,\varepsilon_2)=(\varepsilon_1,\varepsilon_2)\begin{pmatrix}1/2&1/2\\1/2&1/2\end{pmatrix}(=A)$$

（ii）$\mathrm{B}\varepsilon_1=0$

$$\mathrm{B}\varepsilon_2=\varepsilon_2\qquad \therefore \mathrm{B}(\varepsilon_1,\varepsilon_2)=(\varepsilon_1,\varepsilon_2)\begin{pmatrix}0&0\\0&1\end{pmatrix}(=B)$$

（iii）$\mathrm{AB}\text{的矩阵为}AB=\begin{pmatrix}1/2&1/2\\1/2&1/2\end{pmatrix}\begin{pmatrix}0&0\\0&1\end{pmatrix}=\begin{pmatrix}0&1/2\\0&1/2\end{pmatrix}$

7 ③ $\because \varepsilon_i$为i次多项式$(i=0,1,2,\cdots,n-1)$

$\mathrm{P}[x]_n$的一个基

$\mathrm{A}f(x)\to f(x+1)-f(x)$ 所以

$$\mathrm{A}\varepsilon_0=\mathrm{A}(1)=1-1=0$$

$$A\varepsilon_1 = A(x) = (x+1) - x = 1 = \varepsilon_0$$

$$A\varepsilon_2 = A\left(\frac{x(x-1)}{2}\right) = \frac{(x+1)x}{2} - \frac{x(x-1)}{2} = \frac{x}{2}\cdot 2 = x = \varepsilon_1$$

$$A\varepsilon_i = A\left(\frac{x(x-1)(x-2)\cdots(x-i+1)}{i!}\right)$$

$$= \frac{(x+1)x(x-1)\cdots(x-i+2)}{i!} - \frac{x(x-1)(x-2)\cdots(x-i+1)}{i!}$$

$$= \frac{1}{i!}x(x-1)\cdots(x-i+2)\left[(x+1)-(x-i+1)\right]$$

$$= \frac{1}{i!}x(x-1)(x-2)\cdots(x-i+2)[i] = \frac{1}{(i-1)}x(x-1)\cdots(x-i+2) = \varepsilon_{i-1}$$

$$\therefore A(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n) = (\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n)\begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & \vdots \\ \vdots & \vdots & 0 & 0 \\ & & \vdots & \ddots\ 1 \\ 0 & 0 & 0 & 0 \end{pmatrix}(=U)$$

$$D\varepsilon_1 = D\left(e^{ax}\cos bx\right) = ae^{ax}\cos bx + (-b)e^{x}\sin bx = a\varepsilon_1 - b\varepsilon_2,$$

$$D\varepsilon_2 = D\left(e^{ax}\sin x\right) = ae^{ax}\sin x + be^{ax}\cos bx = b\varepsilon_1 + a\varepsilon_2,$$

$$D\varepsilon_3 = D\left(xe^{ax}\cos bx\right) = e^{ax}\cos bx + axe^{ax}\cos bx - bxe^{ax}\sin bx = \varepsilon_1 + a\varepsilon_3 - b\varepsilon_4,$$

$$D\varepsilon_4 = D\left(xe^{ax}\sin bx\right) = e^{ax}\sin bx + axe^{ax}\sin bx + bxe^{ax}\cos bx = \varepsilon_2 + b\varepsilon_3 + a\varepsilon_4,$$

$$D\varepsilon_5 = D\left(\frac{1}{2}x^2e^{ax}\cos bx\right) = xe^{ax}\cos bx + \frac{a}{2}x^2e^{ax}\cos bx - \frac{b}{2}x^2e^{ax}\sin bx = \varepsilon_3 + a\varepsilon_5 - b\varepsilon_6,$$

7 ④ $$D\varepsilon_6 = D\left(\frac{1}{2}x^2e^{ax}\sin bx\right) = xe^{ax}\sin bx + \frac{a}{2}x^2e^{ax}\sin bx + \frac{b}{2}x^2e^{ax}\cos bx = \varepsilon_4 + b\varepsilon_5 - a\varepsilon_6.$$

$$D(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4,\varepsilon_5,\varepsilon_6) = (\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4,\varepsilon_5,\varepsilon_6)\begin{pmatrix} a & b & 1 & 0 & 0 & 0 \\ -b & a & 0 & 1 & 0 & 0 \\ 0 & 0 & a & b & 1 & 0 \\ 0 & 0 & -b & a & 0 & 1 \\ 0 & 0 & 0 & 0 & a & b \\ 0 & 0 & 0 & 0 & -b & a \end{pmatrix}$$

7 ⑤ $$A(\eta_1,\eta_2,\eta_3) = (\eta_1,\eta_2,\eta_3) = \begin{pmatrix} 1 & 0 & 1 \\ 1 & 1 & 0 \\ -1 & 2 & 1 \end{pmatrix}(=B) \qquad \begin{pmatrix} \eta_1 \\ \eta_2 \\ \eta_3 \end{pmatrix} = \begin{pmatrix} -1 & 1 & 1 \\ 1 & 0 & -1 \\ 0 & 1 & 1 \end{pmatrix}$$

$$\begin{pmatrix}\varepsilon_1\\\varepsilon_2\\\varepsilon_3\end{pmatrix}=\begin{pmatrix}1&0&0\\0&1&0\\0&0&1\end{pmatrix}$$

那么 $(\eta_1,\eta_2,\eta_3)=$ $(\varepsilon_1,\varepsilon_2,\varepsilon_3)\begin{pmatrix}-1&1&0\\1&0&1\\1&-1&1\end{pmatrix}(=T)$

$\therefore$ A在$\varepsilon_1,\varepsilon_2,\varepsilon_3$下的矩阵$A$为 $T^{-1}AT=B$

$$\therefore A=TBT^{-1}=\begin{pmatrix}-1&1&0\\1&0&1\\1&-1&1\end{pmatrix}\begin{pmatrix}1&0&1\\1&1&0\\-1&2&1\end{pmatrix}\begin{pmatrix}-1&1&0\\1&0&1\\1&-1&1\end{pmatrix}^{-1}$$

$$=\begin{pmatrix}0&1&-1\\0&2&2\\1&1&2\end{pmatrix}\begin{pmatrix}-1&1&0\\0&1&-1\\1&0&1\end{pmatrix}=\begin{pmatrix}-1&1&-2\\2&2&0\\3&0&2\end{pmatrix}$$

7 ⑥ $\eta_1=(-1,0,2).\eta_2=(0,1,1).\quad \eta_3=(3,-1,0);\quad \varepsilon_1,\varepsilon_2,\varepsilon_3$为标准基

$\mathrm{A}\eta_1=(-5,0,3)$，$\mathrm{A}\eta_2=(0,1,6)$，$\mathrm{A}\eta_3=(-5,1,9)$

解：$(\eta_1,\eta_2,\eta_3)=(\varepsilon_1,\varepsilon_2,\varepsilon_3)\begin{pmatrix}-1&0&3\\0&1&-1\\2&1&0\end{pmatrix}(=T)$

$\mathrm{A}(\eta_1,\eta_2,\eta_3)=(\varepsilon_1,\varepsilon_2,\varepsilon_3)\begin{pmatrix}-5&0&-5\\0&-1&-1\\3&6&9\end{pmatrix}(=C)$

$\therefore \mathrm{A}(\varepsilon_1,\varepsilon_2,\varepsilon_3)=\mathrm{A}((\eta_1,\eta_2,\eta_3)T^{-1})=(\varepsilon_1,\varepsilon_2,\varepsilon_3)CT^{-1}$

$$(C)\begin{pmatrix}-1&0&3\\0&1&-1\\2&1&0\\-5&0&-5\\0&-1&-1\\3&6&9\end{pmatrix}\to\begin{pmatrix}-1&0&0\\0&1&0\\2&1&7\\-5&0&-20\\0&-1&-2\\3&6&24\end{pmatrix}\to\begin{pmatrix}7&0&0\\0&7&0\\14&7&7\\35&0&-20\\0&-7&-2\\-21&42&24\end{pmatrix}\to\begin{pmatrix}7&0&0\\0&7&0\\0&0&7\\-5&20&-20\\-4&-5&-2\\27&18&24\end{pmatrix}$$

$$\therefore CT^{-1}=\frac{1}{7}\begin{pmatrix}-5&20&-20\\-4&-5&-2\\27&18&24\end{pmatrix}$$

7 ⑦（同上）

$\mathrm{A}(\eta_1,\eta_2,\eta_3)=(\varepsilon_1,\varepsilon_2,\varepsilon_3)C=(\eta_1,\eta_2,\eta_3)T^{-1}C$故

$$\begin{pmatrix}-1&0&3&-5&0&-5\\0&1&-1&0&-1&-1\\2&1&0&3&6&9\end{pmatrix}\to\begin{pmatrix}-1&0&3&-5&0&-5\\0&1&-1&0&-1&-1\\0&0&7&-7&7&0\end{pmatrix}\to\begin{pmatrix}1&0&0&2&3&-5\\0&1&0&-1&0&-1\\0&0&1&-1&1&0\end{pmatrix}$$

P322.8 $A_1(E_{11}、E_{12}、E_{21}、E_{22})=\left(\begin{pmatrix}a&0\\c&0\end{pmatrix},\begin{pmatrix}0&a\\0&c\end{pmatrix},\begin{pmatrix}b&0\\a&0\end{pmatrix},\begin{pmatrix}0&b\\0&d\end{pmatrix}\right)A_1$

$$=(E_{11},E_{12},E_{21},E_{22})\begin{pmatrix}a&0&b&0\\0&a&0&b\\c&0&d&0\\0&c&0&d\end{pmatrix}\therefore A_1=\begin{pmatrix}a&0&b&0\\0&a&0&b\\c&0&d&0\\0&c&0&d\end{pmatrix}$$

$$\therefore A_2(E_{11},E_{12},E_{21},E_{22})=\left(\begin{pmatrix}a&b\\0&0\end{pmatrix},\begin{pmatrix}c&d\\0&0\end{pmatrix},\begin{pmatrix}0&0\\a&b\end{pmatrix},\begin{pmatrix}0&0\\v&d\end{pmatrix}\right)A_2$$

$$=(E_{11},E_{12},E_{21},E_{22})\begin{pmatrix}a&c&0&0\\b&d&0&0\\0&0&a&c\\0&c&b&d\end{pmatrix}\therefore A_2=\begin{pmatrix}a&c&0&0\\b&d&0&0\\0&0&a&c\\0&0&b&d\end{pmatrix}$$

$$A_3(E_{11},E_{12},E_{21},E_{22})=(E_{11},E_{12},E_{21},E_{22})\begin{pmatrix}a^2&ac&ab&bc\\ab&ad&b^2&bd\\ac&c^2&ad&cd\\cb&cd&bd&d^2\end{pmatrix}$$

P322 9①在 ε_3、ε_2、ε_1 下的矩阵为

$$P^{-1}(1,3)AP(1,3)=P(1,3)AP(1,3)=\begin{pmatrix}a_{33}&a_{32}&a_{31}\\a_{23}&a_{22}&a_{21}\\a_{13}&a_{12}&a_{11}\end{pmatrix}$$

②在 ε_3、$k\varepsilon_2$、ε_1 下的矩阵为

$$P^{-1}(2(k))AP(2(k))=P_2(\frac{1}{k})AP_2(k)=\begin{pmatrix}a_{11}&ka_{12}&a_{13}\\\frac{a_{21}}{k}&a_{22}&\frac{a_{23}}{k}\\a_{13}&ka_{32}&a_{33}\end{pmatrix}$$

③在 $\varepsilon_1+\varepsilon_2$、$\varepsilon_2$、$\varepsilon_3$ 下的矩阵为

$$P^{-1}(2,1(1)\,AP(2,1(1))=P(2,1(-1)AP(2,1(1))=\begin{pmatrix} a_{11}+a_{12} & a_{12} & a_{13} \\ a_{21}+a_{22}-a_{11}-a_{12} & a_{22}-a_{12} & a_{23}-a_{13} \\ a_{31}+a_{32} & a_{32} & a_{33} \end{pmatrix}$$

P322.10反没有 $l_0,l_1,\cdots,l_{k-1}$ 不全为0，使 $l_1\zeta+l_1\mathrm{A}\zeta+\cdots+l_{k-1}\mathrm{A}^{k-1}\zeta=0$

而 l_i 是 $l_0,l_1\cdots,l_{k-1}$ 第一个非0数，故 $l_i\mathrm{A}^i\zeta+l_{i+1}\mathrm{A}^{i+1}\zeta\cdots+l_{k-1}\mathrm{A}^{k-1}\zeta=0$

两也用 A^{k-i-1} 作用 $\because \mathrm{A}^k\zeta=0 \therefore s>k,\mathrm{A}^s\zeta=0=\mathrm{A}^{s-k}(\mathrm{A}^k\zeta)=\mathrm{A}^{s-k}(0)=0$

则只留下 $l_i\mathrm{A}^{i+k-i-1}\zeta=0\Rightarrow l_i\mathrm{A}^{k-1}\zeta=0$，但， $\mathrm{A}^{k-1}\zeta\neq0$

$\therefore l_i=0$（与 l_i 的选择矛盾！）

故 $\zeta,\mathrm{A}\zeta,\mathrm{A}^2\zeta,\cdots,\mathrm{A}^{k-1}\zeta(k>0)$ 线性无关。

P322 11（由10题）ζ， $\mathrm{A}^{k-1}\zeta,\cdots,\mathrm{A}^{k-1}\zeta$，线性无关，做成空间的一个基

且 $\mathrm{A}(\zeta,\mathrm{A}\zeta,\cdots,\mathrm{A}^{n-1}\zeta)$

$=(\mathrm{A}\zeta,\mathrm{A}^2\zeta,\cdots,\mathrm{A}^{n-1}\zeta,\mathrm{A}^k\zeta)$

$$=(\mathrm{A}\zeta,\mathrm{A}^2\zeta,\cdots,\mathrm{A}^{n-1}\zeta,0)=(\zeta,\mathrm{A}\zeta,\cdots,\mathrm{A}^{n-1}\zeta)\begin{pmatrix} 0 & 0 & \cdots & 0 & 0 \\ 1 & 0 & \cdots & 0 & 0 \\ 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & 0 & 0 \\ 0 & 0 & \cdots & 1 & 0 \end{pmatrix}$$

而为所求证。

P_{323} 13 设 $\varepsilon_1,\ \varepsilon_2,\cdots,\ \varepsilon_n$ 为V的基　$\mathrm{A}\in L(V)$ 且

$$\mathrm{A}(\varepsilon_1,\ \varepsilon_2,\cdots\varepsilon_n)=(\varepsilon_1,\ \varepsilon_2,\cdots\varepsilon_n)A$$

对任意可逆矩阵T　作 $(\eta_1\eta_2\cdots\eta_n)=(\varepsilon_1\varepsilon_2\cdots\varepsilon_n)T$ 仍为基

那么 $\mathrm{A}(\eta_1\eta_2\cdots\eta_n)=(\eta_1\eta_2\cdots\eta_n)(T^{-1}AT)$

由已知 A 在任意基下矩阵相同，故 $A=T^{-1}AT$

即 $TA=AT$

A与任何可逆矩阵可换 特别的令$T=E+E_{ij}$（矩阵单位）

$$A+E_{ij}A=TA=AT=A+AE_{ij}\Rightarrow E_{ij}A=AE_{ij}$$

因此A与任何矩阵可换，所以 $A=kE \qquad (k\in \mathrm{P})$

$$\therefore \mathrm{A}\varepsilon_i=k\varepsilon_i$$

$$\forall\alpha\in V_i\alpha=\sum_{i=1}^{n}a_i\varepsilon_i\Rightarrow \mathrm{A}\alpha=\sum_{i=1}^{n}a_i\mathrm{A}\varepsilon_i=k\sum_{i=1}^{n}a_i\varepsilon_i=k\alpha$$

$$\therefore \mathrm{A}=\mathrm{k}$$

$$P_{323}14\cdot\mathrm{A}(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)=(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)\underbrace{\begin{pmatrix}1&0&2&1\\-1&2&1&3\\1&2&5&5\\2&-2&1&-2\end{pmatrix}}_{=A}$$

14①、

$$(\eta_1,\eta_2,\eta_3,\eta_4)=(\varepsilon_1,\varepsilon_2,\varepsilon_3,\varepsilon_4)\underbrace{\begin{pmatrix}1&0&0&0\\-2&3&0&0\\0&-1&1&0\\1&-1&1&2\end{pmatrix}}_{=T}\quad .\ T^{-1}=\frac{1}{6}\begin{pmatrix}6&0&0&0\\4&2&0&0\\4&2&6&0\\-3&0&-3&3\end{pmatrix}$$

所求矩陈为：

$$B=T^{-1}AT=\frac{1}{6}\begin{pmatrix}6&0&0&0\\4&2&0&0\\4&2&6&0\\-3&0&-3&3\end{pmatrix}\cdot\begin{pmatrix}2&-3&3&2\\-2&2&4&6\\2&-4&104&10\\4&-5&-1&-4\end{pmatrix}=\frac{1}{3}\begin{pmatrix}6&-9&9&6\\2&-4&10&10\\8&-16&40&40\\0&3&-21&-24\end{pmatrix}$$

14②

$$\therefore A\rightarrow\begin{pmatrix}1&0&2&1\\0&2&3&4\\0&2&3&4\\0&-2&-3&-4\end{pmatrix}\therefore 秩(A)=2$$

$$\mathrm{A}V=L(\mathrm{A}\varepsilon,\mathrm{A}\varepsilon_2)$$

若 $\mathrm{A}\zeta=0,\zeta=(\varepsilon_1,\,\varepsilon_2,\,\varepsilon_3,\,\varepsilon_4)X$ ，则 $AX=0$，基础解为$\begin{pmatrix}-4\\-3\\2\\0\end{pmatrix},\begin{pmatrix}-1\\-2\\0\\1\end{pmatrix}$

$$\therefore\zeta_1=-4\varepsilon_1-3\varepsilon_2+2\varepsilon_3,\zeta_1=-\varepsilon_1-2\varepsilon_2+\varepsilon_4$$

$$\therefore \mathrm{A}^{-1}(0)=L(\zeta_1,\,\zeta_2)$$

14③令 $\zeta_3=\varepsilon_1,\zeta_4=\varepsilon_2$，则

$$(\zeta_1,\,\zeta_2,\,\zeta_3,\,\zeta_4)=(\varepsilon_1,\,\varepsilon_2,\,\varepsilon_3,\,\varepsilon_4)\underbrace{\begin{pmatrix}-4&-1&1&0\\-3&-2&0&1\\2&0&0&0\\0&1&0&0\end{pmatrix}}_{=T_1}$$

$$T_1^{-1}=\begin{pmatrix}0&0&\frac{1}{2}&0\\0&0&0&1\\1&0&2&1\\0&1&\frac{3}{2}&2\end{pmatrix},\therefore T_1^{-1}AT_1=\begin{pmatrix}0&0&\frac{1}{2}&1\\0&0&2&-2\\1&0&5&2\\0&1&\frac{9}{2}&1\end{pmatrix}$$

14 ④令 $\xi_1=\mathrm{A}\varepsilon_1,\xi_2=\mathrm{A}\varepsilon_2,\xi_3=\varepsilon_1,\xi_4=\varepsilon_2$

可

$$(\zeta_1,\,\zeta_2,\,\zeta_3,\,\zeta_4)=(\varepsilon_1,\,\varepsilon_2,\,\varepsilon_3,\,\varepsilon_4)\underbrace{\begin{pmatrix}1&0&1&0\\-1&2&0&1\\1&2&0&0\\2&-2&0&0\end{pmatrix}}_{=T1}\,,\therefore T_2^{-1}=\begin{pmatrix}0&0&\frac{1}{3}&\frac{1}{3}\\0&0&\frac{1}{3}&-\frac{1}{6}\\1&0&-\frac{1}{3}&-\frac{1}{3}\\0&1&-\frac{1}{3}&\frac{2}{3}\end{pmatrix}$$

$$\therefore T_2^{-1}AT_2=\frac{1}{6}\begin{pmatrix}0&0&2&2\\0&0&2&-1\\6&0&-2&-2\\0&6&-2&4\end{pmatrix}\begin{pmatrix}5&2&1&0\\4&0&-1&2\\14&4&1&2\\1&2&2&-2\end{pmatrix}=\begin{pmatrix}5&2&1&0\\\frac{9}{2}&1&0&1\\0&0&0&0\\0&0&0&0\end{pmatrix}$$

$\mathrm{P}_{323.}$ 15 ①若 $(\varepsilon_1,\varepsilon_2,\varepsilon_3)T=(\eta_1,\eta_2,\eta_3)$

$$令 c_1=\begin{pmatrix}1&2&1\\0&1&1\\1&0&1\end{pmatrix}\qquad c_2=\begin{pmatrix}1&2&2\\2&2&-1\\-1&-1&-1\end{pmatrix}$$

则会有 $c_1T=c_2$

$$\begin{pmatrix}1&2&1&1&2&2\\0&1&1&2&2&-1\\1&0&1&-1&-1&-1\end{pmatrix}\to\begin{pmatrix}1&0&1&-1&-1&-1\\0&1&1&2&2&-1\\0&2&0&2&3&3\end{pmatrix}\to\begin{pmatrix}1&0&1&-1&-1&-1\\0&2&0&2&3&3\\0&0&1&1&\frac{1}{2}&-\frac{5}{2}\end{pmatrix}\to\begin{pmatrix}1&0&9&-2\\0&1&0&1\\0&0&1&1\end{pmatrix}$$

$$\therefore T=c_1^{-1}c_2=\frac{1}{2}\begin{pmatrix}-4&-3&3\\2&3&3\\2&1&-5\end{pmatrix}$$

15 ② $\because \mathrm{A}\varepsilon_i=\eta_i$ $\qquad\therefore \mathrm{A}(\varepsilon_1,\varepsilon_2,\varepsilon_3)=(\eta_1,\eta_2,\eta_3)=(\varepsilon_1,\varepsilon_2,\varepsilon_3)T$,结果如1中$T$

15 ③ $$\mathrm{A}\left(\varepsilon_1,\varepsilon_2,\varepsilon_3\right)=\left(\left(\varepsilon_1,\varepsilon_2,\varepsilon_3\right)T\right)=\left(\mathrm{A}\left(\varepsilon_1,\varepsilon_2,\varepsilon_3\right)T\right)$$

$$=\left(\left(\varepsilon_1,\varepsilon_2,\varepsilon_3\right)T\right)T=\left(\left(\eta_1,\eta_2,\eta_3\right)T^{-1}\right)T^2=\left(\eta_1,\eta_2,\eta_3\right)T$$

结果仍为 $T=T^{-1}TT$

P324 16 当n=1时显然已成立 $m=2$也易证成立

设n=k时命题成立， 当n=k+1时

若 $i_n=n$,令$T_1=E$,若$i_n\neq n$,设$i_j=n$ $\left(j<n\right)$令$T_1=P_{(j,n)}$（初等矩阵）

那么 对于

$$A=\begin{pmatrix}\lambda_{i1} & & & \\ & \lambda_{i2} & & \\ & & \ddots & \\ & & & \lambda_{in}\end{pmatrix} \text{则} \quad T_1^{-1}AT_1=T_1'AT=\begin{pmatrix}\lambda_{i1} & & & \\ & \ddots & & \\ & & \lambda_{jn} & \\ & & & \lambda_n\end{pmatrix}=\begin{pmatrix}A_1 & \\ & \lambda_n\end{pmatrix}$$

其中 $j_1,j_2\cdots j_{n-1}$为$1.2,n-1$的一个排列由归纳假设必有T_2

$$T_2^{-1}A_1T_2=\begin{pmatrix}\lambda_{i1} & & & \\ & \lambda_{i2} & & \\ & & \ddots & \\ & & & \lambda_{n-1}\end{pmatrix} \qquad \text{令} T=T_1\begin{pmatrix}T_2 & 0\\ 0 & 1\end{pmatrix}\text{则}$$

$$T^{-1}AT=\begin{pmatrix}T_2^{-1} & 0\\ 0 & 1\end{pmatrix}\left(T_1^{-1}AT_1\right)\begin{pmatrix}T_2 & 0\\ 0 & 1\end{pmatrix}=\begin{pmatrix}T_2^{-1} & 0\\ 0 & 1\end{pmatrix}\begin{pmatrix}A_1 & 0\\ 0 & \lambda_n\end{pmatrix}\begin{pmatrix}T_2 & 0\\ 0 & 1\end{pmatrix}=\begin{pmatrix}\lambda_{i1} & & & \\ & \ddots & & \\ & & \lambda_{n-1} & \\ & & & \lambda_n\end{pmatrix}$$ 证毕

P324 17 A^{-1}存在 $\therefore A^{-1}(AB)A=BA$

$\therefore AB\sim BA$

此时若A不可逆，则只有 $f_{AB}(\lambda)=f_{BA}(\lambda)$，没有AB~BA

对于 $f_{AB}(\lambda)=|\lambda E_n-AB|=|\lambda E_n-BA|=f_{BA}(\lambda)$（参见P207 30或P4.58.10.3）

至于 $AB\sim BA$ 简单可取 $A=\begin{pmatrix}1 & 1\\ 1 & 1\end{pmatrix},B=\begin{pmatrix}1 & 1\\ -1 & -1\end{pmatrix}$ 则AB=0，BA= $\begin{pmatrix}2 & 2\\ -2 & -2\end{pmatrix}$

$$T^{-1}(AB)T=0\neq\begin{pmatrix}2&2\\-2&-2\end{pmatrix}=BA$$

P324.18,设 $T_1^{-1}AT_1=B \qquad T_2^{-1}CT_2=D.$令$T=\begin{pmatrix}T_1&\\&T_2\end{pmatrix}$则$T^{-1}=\begin{pmatrix}T_1^{-1}&\\&T_{-2}^{-1}\end{pmatrix}$

$$T^{-1}\begin{pmatrix}A&0\\0&C\end{pmatrix}T=\begin{pmatrix}T_1^{-1}&0\\0&T_2^{-1}\end{pmatrix}\begin{pmatrix}A&0\\0&C\end{pmatrix}\begin{pmatrix}T_1&0\\0&T_2\end{pmatrix}=\begin{pmatrix}B&0\\0&D\end{pmatrix}$$

P324 19 ②求 A 的特征值，特征向量：$\mathrm{A}(\varepsilon_1\varepsilon_2)=(\varepsilon_1\varepsilon_2)\begin{pmatrix}0&a\\-a&0\end{pmatrix}$

$$A=\begin{pmatrix}0&a\\-a&0\end{pmatrix},\qquad f_A(\lambda)=\lambda^2+a^2=(\lambda+ia)(\lambda-ia)$$

对于 $\lambda_1=-ia \qquad (\lambda_1E-A)X=\begin{pmatrix}ia&-a\\a&ia\end{pmatrix}\begin{pmatrix}x_1\\x_2\end{pmatrix}=0,\ \zeta_1=\begin{pmatrix}i\\1\end{pmatrix},\eta_1=k_1\xi_1\ \ (k_1\neq0)$

一切特征向量为 $k_1(i\varepsilon_1+\varepsilon_2)$

对于 $\lambda_2=ia,(\lambda_2E-A)x=\begin{pmatrix}ia&-a\\a&ia\end{pmatrix}\begin{pmatrix}x_1\\x_2\end{pmatrix}=0,\xi_2=\begin{pmatrix}i\\1\end{pmatrix}\ \eta_2=k_2\xi_2\ \ (k_2\neq0)$

当 $\alpha=0,$则$A=0$，$\therefore$数乘变换，特征值为0，特征向量是一切非0向量

P324 19 ③ $\mathrm{A}(\varepsilon_1\ \ \varepsilon_2\ \ \varepsilon_3\ \ \varepsilon_4)=(\varepsilon_1\ \ \varepsilon_2\ \ \varepsilon_3\ \ \varepsilon_4)\begin{pmatrix}1&1&1&1\\1&1&-1&-1\\1&-1&1&-1\\1&-1&-1&1\end{pmatrix}$。 $A=\begin{pmatrix}1&1&1&1\\1&1&-1&-1\\1&-1&1&-1\\1&-1&-1&1\end{pmatrix}$

$f_{\mathrm{A}}(\lambda)=|\lambda E-A|$，由于秩 $(2E-A)=1\Rightarrow$ 重数 $S\geq4-1=3\ \ (P_{7.102,12,4}).$

$\therefore\mathrm{A}$ 有3个特征数 $\lambda_1=\lambda_2=\lambda_3=2$.但 $tr(\mathrm{A})=4,\therefore\lambda_4=4-3\cdot2=-2$

故 $f_{\mathrm{A}}(\lambda)=(\lambda-2)^3(\lambda+2).$

对于 $\lambda_1=2,(\lambda_1E-A)X=\begin{pmatrix}1&-1&-1&-1\\-1&1&1&1\\-1&1&1&1\\-1&1&1&1\end{pmatrix}X=0,X_1=\begin{pmatrix}1\\1\\0\\0\end{pmatrix},X_1=\begin{pmatrix}1\\0\\1\\0\end{pmatrix},X_3=\begin{pmatrix}1\\0\\0\\1\end{pmatrix}$

一切特征向量为 k_1,k_2,k_3 不全为0

$$\xi_1=\begin{pmatrix}\varepsilon_1 & \varepsilon_2 & \varepsilon_3 & \varepsilon_4\end{pmatrix}(k_1x_1+k_2x_2+k_3x_3)=(k_1+k_2+k_3)\varepsilon_1+k_1\varepsilon_2+k_2\varepsilon_3+k_3\varepsilon_4$$ 。

对于 $$\lambda_4=-2.(\lambda_4E-A)X=\begin{pmatrix}-3 & -1 & -1 & -1\\ -1 & -3 & 1 & 1\\ -1 & 1 & -3 & 1\\ -1 & 1 & 1 & -3\end{pmatrix}X=0,\quad X_4=\begin{pmatrix}-1\\1\\1\\1\end{pmatrix}$$ 。

属于 -2 的一切特征向量为

$$\xi_4=k_4(-\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4)\qquad k_4\neq 0.$$

P324 19 ④ $$\mathrm{A}\left(\varepsilon_1\varepsilon_2\varepsilon_3\right)=\left(\varepsilon_1\varepsilon_2\varepsilon_3\right)\begin{pmatrix}5 & 6 & -3\\ -1 & 0 & 1\\ 1 & 2 & -1\end{pmatrix}=A\left(见P_{7.105.10.2}例\right)$$

$$f_A\left(\lambda\right)=\left(\lambda-2\right)\left(\lambda-(\sqrt{3}+1)\right)\left(\lambda+\sqrt{3}-1\right)$$

$$\therefore\lambda_1=2,\lambda_2=+\sqrt{3}+1,\lambda_3=-\sqrt{3}+1$$

对于 $$\lambda_1=2\left(\lambda_1E-A\right)X=\begin{pmatrix}-3 & -6 & +3\\ +1 & 2 & -1\\ -1 & -2 & 3\end{pmatrix}\begin{pmatrix}x_1\\x_2\\x_3\end{pmatrix}=0\qquad\therefore\begin{cases}x_1+2x_2=x_3\\ x_1+2x_2=3x_3\end{cases}$$

$$x_1=\begin{pmatrix}-2\\1\\0\end{pmatrix}$$ 一切属于2的特征向量为 $k_1(-2\varepsilon_1+\varepsilon_2),k_1\neq 0.$

对于 $$\lambda_2=+\sqrt{3}+1,\left(\lambda_2E-A\right)X=\begin{pmatrix}+\sqrt{3}-4 & -6 & +3\\ 1 & +\sqrt{3}+1 & -1\\ -1 & -2 & 2+\sqrt{3}\end{pmatrix}\begin{pmatrix}x_1\\x_2\\x_3\end{pmatrix}=0,x_2=\begin{pmatrix}-3\\1\\\sqrt{3}-2\end{pmatrix}$$

一切属于 $\sqrt{3}+1$ 的特征自量为 $k_2\left(-3\varepsilon_1+\varepsilon_2+\left(\sqrt{3}-2\right)\varepsilon_3\right)\qquad k_2\neq 0$

对于 $$\lambda_3=1-\sqrt{3}\qquad\left(\lambda_3E-A\right)X=\begin{pmatrix}-\sqrt{3}-4 & -6 & +3\\ 1 & -\sqrt{3}+1 & -1\\ -1 & -2 & 2-\sqrt{3}\end{pmatrix}\begin{pmatrix}x_1\\x_2\\x_3\end{pmatrix}=0\qquad x_3=\begin{pmatrix}-3\\1\\-\sqrt{3}-2\end{pmatrix}$$

$\therefore$一切属于 $-\sqrt{3}+1$ 的特征向量为 $k_3\left(-3\varepsilon_1+\varepsilon_2-\left(\sqrt{3}+2\right)\varepsilon_3\right)\qquad k_3\neq 0$

$$\mathrm{A}\left(\varepsilon_1\varepsilon_2\varepsilon_3\right)=\left(\varepsilon_1\varepsilon_2\varepsilon_3\right)\begin{pmatrix}0&0&1\\0&1&0\\1&0&0\end{pmatrix}$$

P324 19 ⑤

$$f_A(\lambda)=\begin{vmatrix}\lambda&0&-1\\0&\lambda-1&0\\-1&0&\lambda\end{vmatrix}=\left(\lambda^1-1\right)\left(\lambda^2-1\right)=\left(\lambda-1\right)^2\left(\lambda+1\right)$$

特征值为 $\lambda_1=-1,\lambda_2=\lambda_3=+1$

对于 $\lambda_1=-1,\left(\lambda_1E-A\right)X=\begin{pmatrix}-1&0&-1\\0&-2&0\\-1&0&-1\end{pmatrix}X=0.X_1=\begin{pmatrix}1\\0\\-1\end{pmatrix}$,一切为$\left(k_1\neq0\right)$ $\quad k_1\left(\varepsilon_1-\varepsilon_3\right)$

对于 $\lambda_2=1,\left(\lambda_2E-A\right)X=\begin{pmatrix}1&0&-1\\0&0&0\\-1&0&1\end{pmatrix}X=0,X_2=\begin{pmatrix}0\\1\\0\end{pmatrix},X_3=\begin{pmatrix}1\\0\\1\end{pmatrix}$

一切特征向量为 $\left(\varepsilon_1,\varepsilon_2,\varepsilon_3\right)\left(k_2x_2+k_3x_3\right)=k_2\varepsilon_1+k_2\varepsilon_2+k_3\varepsilon_3,k_2,k_3$不全为0

P324 19 ⑥ $\mathrm{A}\left(\varepsilon_1\quad\varepsilon_2\quad\varepsilon_3\right)=\left(\varepsilon_1\quad\varepsilon_2\quad\varepsilon_3\right)A$, $A=\begin{pmatrix}0&2&1\\-2&0&3\\-1&-3&0\end{pmatrix}$（反对称）

解 $f_A(\lambda)=\lambda^3+14\lambda\quad\therefore\lambda_1=0,\lambda_2=\sqrt{14}i,\lambda_3=-\sqrt{14}i$

对于 $\lambda_1=0.(\lambda_1E-A)X=\begin{pmatrix}0&-2&-1\\2&0&-3\\1&3&0\end{pmatrix}X=0,X_1=\begin{pmatrix}3\\-1\\2\end{pmatrix}$ $\quad k_1(3\varepsilon_1-\varepsilon_2+2\varepsilon_3)\ \ k_1\neq0$

对于 $\lambda_2=\sqrt{14}i$

$$(\lambda_2E-A)x=\begin{pmatrix}\sqrt{14}i&-2&-1\\2&\sqrt{14}i&-3\\1&3&\sqrt{14}i\end{pmatrix}X=0,X_2=\begin{pmatrix}3+2\sqrt{14}i\\13\\2-3\sqrt{14}i\end{pmatrix}$$

一切特征向量为 $k_2\left((3+2\sqrt{14}i)\varepsilon_1+13\varepsilon_2+(2-3\sqrt{14}i)\varepsilon_3\right)\quad k_2\neq0$

对于 $\lambda_3=-\sqrt{14}i$

$$(\lambda_3E-A)X=\begin{pmatrix}-\sqrt{14}i&-2&-1\\2&-\sqrt{14}i&-3\\1&3&-\sqrt{14}i\end{pmatrix}X=0,X_3=\begin{pmatrix}3-2\sqrt{14}i\\13\\2+3\sqrt{14}i\end{pmatrix}.$$

一切特征向量为 $k_3\left((3-2\sqrt{14}i)\varepsilon_1+13\varepsilon_2+(2+3\sqrt{14}i)\varepsilon_3\right),\quad k_3\neq 0.$，

P325 19 ⑦ $\mathrm{A}\left(\varepsilon_1\varepsilon_2\varepsilon_3\right)=\left(\varepsilon_1\varepsilon_2\varepsilon_3\right)\begin{pmatrix}3&1&0\\-4&-1&0\\4&-8&-2\end{pmatrix}\qquad A=\begin{pmatrix}3&1&0\\-4&-1&0\\4&-8&-2\end{pmatrix}$

$$f_A(\lambda)=\begin{pmatrix}\lambda-3&-1&0\\4&\lambda+1&0\\-4&8&\lambda+2\end{pmatrix}=(\lambda+2)\left(\lambda^2-2\lambda+1\right)=(\lambda+2)(\lambda-1)^2$$

特征值为 $\lambda_1=1,\lambda_2=-2$

对于$\lambda_1=1,\quad (E-A)X=\begin{pmatrix}-2&-1&0\\4&2&0\\-4&8&3\end{pmatrix}X=0,\quad X_1=\begin{pmatrix}3\\-6\\20\end{pmatrix}$,一切为$k_1\left(3\varepsilon_1-6\varepsilon_2+20\varepsilon_3\right)\qquad k_1\neq 0$

对于$\lambda_2=-2,(E-A)X=\begin{pmatrix}-5&-1&0\\4&-1&0\\-4&8&0\end{pmatrix}X=0,X_2=\begin{pmatrix}0\\0\\1\end{pmatrix}$一切属于$\lambda_2=-2$的特征

向量为$k_2\varepsilon_3.(k_2\neq 0)$

P325 20 ①由定理8推论1．取其 $4\varepsilon_1-5\varepsilon_2,\varepsilon_1+\varepsilon_2$，即使 A 的矩阵对角化，取 $T=\begin{pmatrix}4&1\\-5&1\end{pmatrix}.$ 则

$$T^{-1}AT=\begin{pmatrix}-2&0\\0&7\end{pmatrix}.$$

P325 20 ②（见7.106.11.3）可以对角化，取基 $i\varepsilon_1+\varepsilon_2,-i\varepsilon_1+\varepsilon_2$ 即可

取 $T=\begin{pmatrix}i&-i\\1&1\end{pmatrix}$ 则 $T^{-1}AT=\begin{pmatrix}-ia&0\\0&ia\end{pmatrix}$

P325 20 ③$\because \dim V_2=3;\dim V_{-2}=1$故可以对角化，取基

$\varepsilon_1+\varepsilon_2$，$\varepsilon_1+\varepsilon_3$，$\varepsilon_1+\varepsilon_4$，$-\varepsilon_1+\varepsilon_2+\varepsilon_3+\varepsilon_4$ 即可

令 $T=\begin{pmatrix}1&1&1&-1\\1&0&0&1\\0&1&0&1\\0&0&1&1\end{pmatrix}$,则 $T^{-1}AT=\begin{pmatrix}2&&&\\&2&&\\&&2&\\&&&-2\end{pmatrix}$

P325 20 ④（见7.106.11.3）有3个根，可以对角化，取基 $-2\varepsilon_1+\varepsilon_2, -3\varepsilon_1+\varepsilon_2+(\sqrt{3}-2)\varepsilon_3$

$-3\varepsilon_1+\varepsilon_2-(\sqrt{3}+2)\varepsilon_3$，即可. $T=\begin{pmatrix}-2 & -3 & -3\\ 1 & 1 & 1\\ 0 & \sqrt{3}-2 & -\sqrt{3}-2\end{pmatrix}$ 则 $T^{-1}AT=\begin{pmatrix}2 & & \\ & 1+\sqrt{3} & \\ & & 1-\sqrt{3}\end{pmatrix}$

P325 20 ⑤（见7.106.11.4） $\dim V_{-1}+\dim V_1=1+2=3=n$ 可以对角化，取基

$\varepsilon_1-\varepsilon_3, \varepsilon_2, \varepsilon_1+\varepsilon_3$

即可 令 $T=\begin{pmatrix}1 & 0 & 1\\ 0 & 1 & 0\\ -1 & 0 & 1\end{pmatrix}$ 则 $T^{-1}AT=\begin{pmatrix}-1 & & \\ & 1 & \\ & & 1\end{pmatrix}$

P325 20 ⑥有3个（n 个）特征根，可以对角化，取基 $\eta_1=3\varepsilon_1-\varepsilon_2+2\varepsilon_3$

$\eta_2=(3+2\sqrt{14}i)\varepsilon_1+13\varepsilon_2+(2-3\sqrt{14}i)\varepsilon_3$， $\eta_3=(3-2\sqrt{14}i)\varepsilon_1+13\varepsilon_2+(2+3\sqrt{14}i)\varepsilon_3$

即可，令 $T=\begin{pmatrix}3 & 3+\sqrt{14}i & 3-2\sqrt{14}i\\ -1 & 13 & 13\\ 2 & 2-3\sqrt{14}i & 2+3\sqrt{14}i\end{pmatrix}$, 则 $T^{-1}AT=\begin{pmatrix}0 & & \\ & \sqrt{14}i & \\ & & -\sqrt{14}i\end{pmatrix}$

P325 20 ⑦（见7，106，11.4） A 只有 2 个特征值 $1,-2$，且

$\dim V_{+1}=1$ $\dim V_{-2}=1$ 之和为 2 小于空间维数

故 A 在任何基下的矩阵不是对角形，即 A 不与对角矩阵相似.

设 $A\begin{pmatrix}x_1 & 3 & 0\\ x_2 & -6 & 0\\ x_3 & 20 & 1\end{pmatrix}=\begin{pmatrix}x_1 & 3 & 0\\ x_2 & -6 & 0\\ x_3 & 20 & 1\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 1 & 1 & 0\\ 0 & 0 & -2\end{pmatrix}$

可解出 $x_1=1, x_2=1, x_3=-\dfrac{8}{3}$

令 $T=\begin{pmatrix}1 & 3 & 0\\ 1 & -6 & 0\\ -8/3 & 20 & 1\end{pmatrix}$ 则 $|T|=-9\neq 0, T$ 可逆， $\therefore A=T\begin{pmatrix}1 & 0 & 0\\ 1 & 1 & 0\\ 0 & 0 & -2\end{pmatrix}T^{-1}$

同样也有 $A^k=T\begin{pmatrix}1 & 0 & 0\\ k & 1 & 0\\ 0 & 0 & (-2)^k\end{pmatrix}T^{-1}$

P325.21证：取 $p[x]$ 的基 令 $\xi=f(x)=x^{n-1}$，则 $D^{n-1}\xi\neq 0$

$D^n=0, \therefore D$ 在某组下的矩阵为

$$\therefore f_D(\lambda)=\lambda^n \qquad \begin{pmatrix} 0 & & & & \\ 1 & 0 & & & \\ & 1 & \ddots & & \\ & & \ddots & \ddots & \\ & & & 1 & 0 \end{pmatrix} = U(\because n>1)\therefore U\neq 0)$$

反设，有T可逆，使 $$T^{-1}UT=\begin{pmatrix} a_1 & & & \\ & a_2 & & \\ & & \ddots & \\ & & & a_n \end{pmatrix}=B,$$

则 $f_u(\lambda)=f_B(\lambda)=\lambda^n=(\lambda-a_1)(\lambda-a_2)\cdots(\lambda-a_n)\Rightarrow a_1=a_2=\cdots a_n=0$

$\therefore B=0\Rightarrow U=TBT^{-1}=0$ 矛盾！（$\because n>1$）

P325.22 $$A=\begin{pmatrix} 1 & 4 & 2 \\ 0 & -3 & 4 \\ 0 & 4 & 3 \end{pmatrix}, \qquad \begin{aligned} & f_A(\lambda)=(\lambda-1)(\lambda^2-25)=(\lambda-1)(\lambda-5)(\lambda+5) \\ & \therefore \lambda_1=1,\lambda_2=5,\lambda_3=-5 \end{aligned}$$

$$(\lambda_1E-A)X=\begin{pmatrix} 0 & -4 & -2 \\ 0 & 4 & -4 \\ 0 & -4 & -2 \end{pmatrix}, X=0, X_1=\begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}, \ (\lambda_2E-A)X=\begin{pmatrix} 4 & -4 & -2 \\ 0 & 8 & -4 \\ 0 & -4 & -2 \end{pmatrix}, X=0, X_1=\begin{pmatrix} 2 \\ 1 \\ 2 \end{pmatrix}.$$

$$(\lambda_3E-A)X=\begin{pmatrix} -6 & -4 & -2 \\ 0 & -2 & -4 \\ 0 & -4 & -8 \end{pmatrix}, X=0, X_1=\begin{pmatrix} 1 \\ -2 \\ 1 \end{pmatrix}, \text{取}\ T=\begin{pmatrix} 1 & -1 & 2 \\ 0 & -2 & 1 \\ 0 & 1 & 2 \end{pmatrix} \text{则}\ T^{-1}AT=\begin{pmatrix} 1 & & \\ & -5 & \\ & & 5 \end{pmatrix}$$

$$T^{-1}=\begin{pmatrix} 1 & 0 & -1 \\ 0 & -2/5 & 1/5 \\ 0 & 1/5 & 2/5 \end{pmatrix}$$

$$A^k=T^{-1}D^kT=\begin{cases} \begin{pmatrix} 1 & 0 & -1+5k \\ 0 & 5k & 0 \\ 0 & 0 & 5k \end{pmatrix} & k\text{为偶数} \\ \begin{pmatrix} 1 & 4.5^{k-1} & -1+3.5^{k-1} \\ 0 & -3.5^{k-1} & 4.5^{k-1} \\ 0 & 4.5^{k-1} & 3.5^{k-1} \end{pmatrix} & k\text{为奇数} \end{cases}$$

P325.23 ① $T_1=\begin{pmatrix}1&2&0&0\\2&3&0&0\\1&1&1&0\\1&0&0&1\end{pmatrix},T_1^{-1}=\begin{pmatrix}-3&2&0&0\\-2&-1&0&0\\+1&-1&1&0\\+3&-2&0&1\end{pmatrix},T_1^{-1}AT=T_1^{-1}\begin{pmatrix}0&0&-4&3\\0&0&-3&2\\0&0&9/2&-5/2\\0&0&11&-7\end{pmatrix}$

P325 23 ② $f_A(\lambda)=f_A(\lambda)=\begin{pmatrix}\lambda&0&-6&5\\0&\lambda&5&-4\\0&0&\lambda-\frac{7}{2}&3/2\\0&0&-5&\lambda+2\end{pmatrix}$ $=\begin{pmatrix}0&0&-&-5\\0&0&-5&4\\0&0&7/2&-3/2\\0&0&5&-2\end{pmatrix}=B$

$=\frac{1}{2}\lambda^2(2\lambda-1)(\lambda-1);\lambda_1=1,\lambda_2=\frac{1}{2},\lambda_3=\lambda_4=0$

$(\lambda_1E-B)X=0$ $(\lambda_2E-B)X=0$ $(\lambda_3E-B)X=0$

得 $X_1=\begin{pmatrix}-7\\5\\3\\5\end{pmatrix}$ 得 $X_2=\begin{pmatrix}-8\\+6\\1\\2\end{pmatrix}$ 得 $X_3=\begin{pmatrix}1\\0\\0\\0\end{pmatrix},X_4=\begin{pmatrix}0\\1\\0\\0\end{pmatrix}$

对应到 $\lambda_1=1,\zeta_1=(\eta_1,\ \eta_2,\ \eta_3,\ \eta_4)x_1=(\varepsilon_1,\ \varepsilon_2,\ \varepsilon_3,\ \varepsilon_4)\begin{pmatrix}3\\1\\1\\-2\end{pmatrix}_{=T_1X_1}$

对应于 $\lambda_2=\frac{1}{2},\zeta_2=(\eta_1,\eta_2,\eta_3,\eta_4)x_2=(\varepsilon_1,\ \varepsilon_2,\ \varepsilon_3,\ \varepsilon_4)T_1X_2=(\varepsilon_1,\ \varepsilon_2,\ \varepsilon_3,\ \varepsilon_4)\begin{pmatrix}4\\2\\-1\\-6\end{pmatrix}$

对应于 $\lambda_3=\lambda_4=0,\zeta_3:T_1X_3=\begin{pmatrix}1\\2\\1\\1\end{pmatrix}$ $\zeta_4:T_1X_4=\begin{pmatrix}2\\3\\1\\1\end{pmatrix}$

P325 23 ③取 $T=\begin{pmatrix}3&4&1&2\\1&2&2&3\\1&-1&1&1\\-2&-6&1&0\end{pmatrix}$，则 $T^{-1}AT=\begin{pmatrix}1&&&\\&\frac{1}{2}&&\\&&0&\\&&&0\end{pmatrix}$

P325 24 ① $\because A\varepsilon_1=\lambda_1\varepsilon_1,A\varepsilon_2=\lambda_2\varepsilon_2,\lambda_1\neq\lambda$； ε_1， $\varepsilon_2\neq0$

若 $\varepsilon_1+\varepsilon_2$为A的特征向量,设$A(\varepsilon_1+\varepsilon_2)=\lambda_0(\varepsilon_1+\varepsilon_2)$

则 $\lambda_0(\varepsilon_1+\varepsilon_2)=A(\varepsilon_1+\varepsilon_2)=A\varepsilon_1+A\varepsilon_2=\lambda_1\varepsilon_1+\lambda_2\varepsilon_2$

$\therefore(\lambda_0-\lambda_1)\varepsilon_1+(\lambda_0-\lambda_2)\varepsilon_2=0,\quad \because\lambda_2\neq\lambda_2\ \therefore\lambda_0-\lambda_1,\lambda_0-\lambda_2$不全为0.

故$\varepsilon_1,\varepsilon_2$线性相关,不防设$\varepsilon_1=k\varepsilon_2$

$\therefore A\varepsilon_1=A(k\varepsilon_2)=kA\varepsilon_2=k(\lambda_2\varepsilon_2)=\lambda_2(k\varepsilon_2)=\lambda_2\varepsilon_i(=\lambda_1\varepsilon_1)$

$\therefore(\lambda_1-\lambda_2)\varepsilon_1=0\Rightarrow(\varepsilon_1\neq0)\lambda_1=\lambda_2$矛盾!

$\therefore\varepsilon_1+\varepsilon_2$不是A的特征向量.

P325 24 ②既然V中所有向量为特征向量，若存在$\varepsilon_1(\neq0),\varepsilon_2(\neq0)$使$A\varepsilon_1=\lambda_1\varepsilon_1$

$A\varepsilon_2=\lambda_2\varepsilon_2(\lambda_1\neq\lambda_2)$所有非零向量$\alpha$，必有同一个数$k$使，$A\alpha=k\alpha$显然$A0=k0$

所以对一切$\alpha\in V$: $\qquad A\alpha=k\alpha\Rightarrow A=\mathrm{k}$

P326 25 ①$\alpha\in V_{\lambda o}$，则$A\alpha=\lambda_0\alpha,$而$A(B\alpha)=(AB)\alpha=(BA\alpha)=B(A\alpha)$

$=B(\lambda_0\alpha)=\lambda_0(B\alpha)\qquad\therefore B\alpha\in V_{\lambda_0}$

因此$V_{\lambda_0}\in S_V^B$

25 ②在C中$f_A(\lambda)$至少有一个特征根λ_a,令$W=V_a$,是A的属于A_a的特征子空间，则$\alpha\in W,A\alpha=\lambda_a\alpha$

又因为（由上小题①）$W\in SV_V^B$,考虑$B_W=B_1$，则$B_1\in L(W)$，而$f_{B_1}(\lambda)$在C中至少有一个特征值入。

必有一个向量$\zeta\in W,\zeta\neq0$，使$B_1(\zeta)=\lambda_1\zeta,\therefore B\zeta=B_1\zeta=\lambda_b\zeta$，$A\zeta=\lambda_a\zeta$

P326 26

$$\because A(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n)=(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n)\begin{pmatrix}\lambda_0 & & & & \\ 1 & \lambda_0 & & & \\ & 1 & \ddots & & \\ & & \ddots & \lambda_0 & \\ & & & 1 & \lambda_0\end{pmatrix}$$

26①设$W\in S_V^A,\varepsilon_1\in W\Rightarrow\varepsilon_2=A\varepsilon_1\in W,\varepsilon_3=A\varepsilon_2-\lambda_0\varepsilon_2\in W,\cdots,$

$\varepsilon_n=A\varepsilon_{n-1}-\lambda_0\varepsilon_{n-1}\in W\Rightarrow W\supseteq L(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n)=V,\therefore W=V$

26② $f_A(\lambda)=(\lambda-\lambda_0)^n$，$\therefore A$只有一个特值，解$(\lambda_0E-A)x=0,$得

$x_0 = k\begin{pmatrix}0\\0\\ \vdots\\1\end{pmatrix}, \therefore$ 的属于 λ_0 的一切特征向量为 $k\varepsilon_n : (k \neq 0)$

设W为 $\mathrm{A}-$ 子空间，则 $\mathrm{A}W$ 在W中必有一个特征向量 $\zeta, \in W$

$\therefore \mathrm{A}\zeta = \mathrm{A}W(\zeta) = \lambda_1\zeta \Rightarrow \lambda_1 = \lambda_0 \Rightarrow \zeta = k_1\varepsilon_n \qquad k_1 \neq 0$

$\therefore \varepsilon_n = \dfrac{1}{k_1}\zeta \in W$

26 ③若 $V = V_1 + V_2$，而 $V_1, V_2 \in S_V^{\mathrm{A}}$，于是 $\varepsilon_n \in V_1, \varepsilon_n \in V_2 \Rightarrow V_1 \cap V_2 \neq \{0\}$

$\therefore V_1 + V_2$ 不是直和。

P326 27① A= $\begin{pmatrix}0 & 0 & 1\\0 & 1 & 0\\1 & 0 & 0\end{pmatrix}, f_A(\lambda) = (\lambda-1)(\lambda^2-1) = (\lambda^2-1)(\lambda+1)$

$m_A(\lambda) \mid f_A(\lambda), \therefore m_A(\lambda) = (\lambda-1), (\lambda-1)^2, \lambda+1, \lambda^2-1$ 或 $f_A(\lambda)$

$\because A \pm E \neq 0, \therefore m_A(\lambda) \neq (\lambda-1), \neq \lambda+1$

$(A-E)^2 = \begin{pmatrix}-1 & 0 & 1\\0 & 0 & 0\\1 & 0 & -1\end{pmatrix}^2 = \begin{pmatrix}2 & 0 & -2\\0 & 0 & 0\\-2 & 0 & 2\end{pmatrix} \neq 0, \therefore m_A(\lambda) \neq (\lambda-1)^2$

又 $\because A^2 = E \Rightarrow m_A(x) = x^2 - 1$

P326.27 ② $A = \begin{pmatrix}3 & -1 & -3 & 1\\-1 & 3 & 1 & -3\\3 & -1 & -3 & 1\\-1 & 3 & 1 & -3\end{pmatrix}, \quad f_A(x) = \begin{pmatrix}x-3 & 1 & 3 & -1\\1 & x-3 & -1 & 3\\-3 & 1 & x+3 & -1\\1 & -3 & -1 & x+3\end{pmatrix} =$

$\begin{pmatrix}x-3 & 1 & 3 & -1\\1 & x-3 & -1 & 3\\-x & 0 & x & 0\\0 & -x & 0 & x\end{pmatrix} = \begin{pmatrix}x & 1 & 3 & -1\\0 & x & -1 & 3\\0 & 0 & x & 0\\0 & 0 & 0 & x\end{pmatrix} = x^4$

$m_A(x) f_A(x), \therefore m_A(x) = x, x^2, x^3$ 或 x^4

$$\because A^2=\begin{pmatrix}3&-1&-3&1\\-1&3&1&-3\\3&-1&-3&1\\-1&3&1&-3\end{pmatrix}\begin{pmatrix}3&-1&-3&1\\-1&3&1&-3\\3&-1&-3&1\\-1&3&1&-3\end{pmatrix}=\begin{pmatrix}0&0&0&0\\0&0&0&0\\0&0&0&0\\0&0&0&0\end{pmatrix}=0$$

，而 $A'\neq 0$

$\therefore m_A(x)=x^2$

P_{326} 补1. ① $\left(A^2=A.B^2=B\right)$ 且 $\left(A+B\right)^2=A+B$,证明AB=0.

证： $A^2+AB+BA+B^2=A+B\Rightarrow AB+BA=0$

$\therefore\left(AB+BA\right)A=0\Rightarrow ABA+BA=0$

$A\left(AB+BA\right)=0\Rightarrow AB+ABA=0$

$\therefore BA=-AB=AB$

$AB+BA=0\Rightarrow 2AB=0\Rightarrow AB=0$

补1②

$A^2=A,B^2=B,AB=BA$ 证明 $\left(A+B-AB\right)^2=A+B-AB$

$\because$ 可交换乘故 $\left(A+B-AB\right)^2$

$=A^2+B^2+A^2B^2+2AB-2A^2B-2AB^2$

证 $=A+B+AB+2AB-2AB-2AB=A+B-AB$

P_{326} 补2，证：由Th2(i) (ii) 可以 $L(V)\overset{\psi}{\cong}P^{n\times n}$，所以 $\dim L(V)=n^2$.

P_{326} 补 3① V_P $A\in L\left(V\right),\dim V=n,$ $\left(基\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n.A在\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n下的矩阵为A\right)$ $L\left(V\right)\cong P^{n\times n},$

$\therefore \dim L(V)=n^2$

因此：n^2+1个线性变换

$$\mathrm{E},\mathrm{A},\mathrm{A}^2,\cdots,\mathrm{A}^n,\cdots,\mathrm{A}^{n^2}$$

线性相关，即存在$a_o,a_1,a_2,\cdots a_n,a_{n^2}$不全为0,使

$$a_o\mathrm{E}+a_1\mathrm{A}+a_2\mathrm{A}^2+\cdots+a_n{}^2\mathrm{A}^n+a_n{}^2\mathrm{A}^{n^2}=0$$

故作 $f(x)=a_o+a_1x+a_2x^2-1\cdots+a_{n^2}x^{n^2}$,则$f(x)\neq 0$,且$\partial(f(x))\leq n^2$

则有 $f(\mathrm{A})=0$

P_{327} 补3② 因为 $d(x)=(\lambda(x)f(x)+v(x)g(x))$

$$\therefore d(\mathrm{A})=\lambda(\mathrm{A})f(\mathrm{A})+v(\mathrm{A})g(\mathrm{A})=0+0=0$$

P_{327} 补3 ③$\Rightarrow$若A可逆,则$\exists\mathrm{B},\mathrm{AB}=\mathrm{BA}=\mathrm{E}$

$\because$必有$f(x)\neq a$ 使$f(\mathrm{A})=0$, 设$f(x)=k^kg(x)$,$g(x)$为常数项$\neq 0$.

$\therefore f(\mathrm{A})=\mathrm{A}^kg(\mathrm{A})\Rightarrow \mathrm{B}^kf(\mathrm{A})=\mathrm{B}^k\mathrm{A}^kg(\mathrm{A})=g(\mathrm{A})\Rightarrow g(\mathrm{A})=0.$

$g(\mathrm{x})$即为所求

"$\Leftarrow$" 若有$f(x)=a_o+a_1+a_1x+\cdot+a_nx^m$且$a_o\neq 0$, $f(\mathrm{A})=0$

$$\therefore a_0\mathrm{E}+\mathrm{A}\left(a_1\mathrm{E}+a_2\mathrm{A}+\cdots+a_m\mathrm{A}^{m+1}\right)=0$$

而$\mathrm{A}\left(-\frac{1}{ao}\left(a_1\mathrm{E}+a_2\mathrm{A}+\cdots+a_m\mathrm{A}^{m-1}\right)\right)=\mathrm{E}$(交换任置)

定义:A可逆 且$\mathrm{A}^{-1}=-\frac{1}{a_o}\left(a_1\mathrm{E}+a_2\mathrm{E}+a_2\mathrm{A}+\cdot+a_m\mathrm{A}^{m-1}\right)$

P_{327} 补4 ① A 可逆 λ_o为A特征值, $\mathrm{A}\in L(V)$,则A必为单射(1−1的)

因为有$\xi\neq 0$, $\mathrm{A}\xi=\lambda_o\xi$,若$\lambda_o=0$.则

$$\mathrm{A}\xi=0$$

于是0的原像不唯一，不是单射，矛盾！

补4②设λ为A 的特征值，则有$\xi\neq 0$ $\mathrm{A}\xi=\lambda\xi,(\lambda\neq 0)$

$$\therefore \mathrm{A}^{-1}\left(/ A\xi\right)=\left(\mathrm{A}^{-1}\mathrm{A}\right)\left(\xi\right)=\xi$$

$$=\mathrm{A}^{-1}\left(\lambda\xi\right)=\lambda\mathrm{A}^{-1}\left(\xi\right) \qquad \therefore \mathrm{A}^{-1}\left(\xi\right)=\frac{1}{\lambda}\xi$$

即$\frac{1}{\lambda}$为A^{-1}的一个特征值.

P327 补5“$\Rightarrow$”，$\because |\mathrm{A}|=\lambda_1\lambda_1\cdots\lambda_n$ $\quad |\mathrm{A}|=0$ 必有某个 $\lambda_i=0$

“$\Leftarrow$”若某个 $\lambda_i=0$，则$|\mathrm{A}|=\lambda_1\lambda_2\cdots\lambda_n=0$

另证：设 A 在基 $\varepsilon_1,\varepsilon_1\cdots\varepsilon_n$ 下的矩阵为A，则

$\therefore |\mathrm{A}|=0 \Leftrightarrow |\mathrm{A}|=0 \Leftrightarrow \mathrm{A}x=0$ 有非0解 ζ

$\Leftrightarrow \exists\xi\neq 0 \qquad \mathrm{A}\zeta=0=0\cdot\zeta \Leftrightarrow 0$ 是一个特征值

P327 补6 ① $\because A=\begin{pmatrix} a_{11} & & & 0 \\ & a_{22} & & \\ & & \ddots & \\ a_{2j} & & & a_{nn} \end{pmatrix} \therefore f_A(\lambda)=\prod_{i=1}^{n}(\lambda-a_{ii}).$

有n个不同的特征根，由定理8,推论1，则 A 与对角矩阵相似

补6 ② $f_A(\lambda)=\prod_{i=1}^{n}(\lambda-a_{ii})=(\lambda-a_{11})^n$ 只有一个n重根

根据推论4，（7，107，12.3）应：$T^{-1}AT$ 对角 $\Leftrightarrow \sum_{i=1}^{n}秩(a_{ii}E-A)=秩(a_{11}E-A)=0$

但 $秩(a_{11}E-A)=秩\begin{pmatrix} 0 & & \\ & \ddots & \\ -a_{i_0j_0} & & 0 \end{pmatrix}\neq 0 \qquad \because (a_{i_0j_0}\neq 0, i_0\neq j_0)$

$\therefore A$不能与对角矩阵相似.

P327.补7 $A\in C^{nxn}$ 则 $\exists T\in C^{nxn}$，不可逆，且 $T^{-1}AT$ 为上三角矩阵，证：（归纳片）当 $n=1$ 时，已经成立，设 $n-1$ 阶时命运成立。考虑 n 级情形。

$f_A(\lambda)\in[x]$，则存在一复根 $\lambda_1, f_A(\lambda_1)=0$，设 ε_1 为A的属于 λ_1 的特征向虚，$A\xi_1=\lambda_1\xi_1$

扩充 $\xi_1,\xi_2\cdots\xi_n$ 为 C^n 的一个基的

$\therefore \mathrm{A}\xi_{\mathrm{i}} \leftarrow \xi_1 \cdots \xi_n$

$$A(\xi_{31}、\xi_{32}、\xi_{33}) = (A\xi_{31}、\xi_{32} \cdots \xi_{3n}) = (\xi_{31}、\xi_{32}、\xi_{33})\begin{pmatrix} \lambda_1 & d_{12} & d_{1m} \\ 0 & A_1 & \\ 0 & & \end{pmatrix}$$

令 $T_1 = \left(\xi_1 \cdots \xi_n\right)$ 可逆 $AT_1 = T_1\begin{pmatrix} \lambda_1 & \alpha \\ 0 & A_1 \end{pmatrix}$

A_1是 $n-1$级矩阵，由归纳假设，存在T_2使 $T^{2^{-1}}\,T_2$ 为上 Δ

令 $T = T_1\begin{pmatrix} 1 & 0 \\ 0 & T_2 \end{pmatrix}$ 则 $T^{-1}AT = \begin{pmatrix} 1 & 0 \\ 0 & T_2^{-1} \end{pmatrix} T_1^{-1}AT_1 \begin{pmatrix} 1 & 0 \\ 0 & T_2 \end{pmatrix}$

$$= \begin{pmatrix} 1 & 0 \\ 0 & T_2^{-1} \end{pmatrix} T_1^{-1}T_1 \begin{pmatrix} \lambda_1 & \alpha \\ 0 & A_1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ 0 & T_2 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & T_2^{-1} \end{pmatrix}\begin{pmatrix} \lambda_1 & \alpha \\ 0 & A_1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ 0 & T_2 \end{pmatrix}$$

$= \begin{pmatrix} \lambda_1 & \alpha \\ 0 & T_2^{-1}A \end{pmatrix}\begin{pmatrix} 1 & 0 \\ 0 & T_2 \end{pmatrix} = \begin{pmatrix} \lambda_1 & \alpha T_2 \\ 0 & T_2^{-1}AT_2 \end{pmatrix} =$ 仍为上△

由假纳假设，证毕

P327 补8 $\mathrm{A}_1, \mathrm{A}_2 \cdots \mathrm{A}_s \in L(V)$ 两两不同，则 $\exists \alpha \in V$，使 $\mathrm{A}_1\alpha, \mathrm{A}_2\alpha, \cdots \mathrm{A}_s\alpha$ 两两不同，（看见这题，想起什么，chap6补5）

证：作 $\mathrm{B}_{\mathrm{ij}} = \mathrm{A}_{\mathrm{i}} - \mathrm{A}_{\mathrm{j}} (i < j)$

则诸 $\mathrm{B}_{\mathrm{ij}}(\neq 0)$ 是 $L(V)$ 中 $\dfrac{5}{2}(s-1)$ 个非零线性变换

令 $V_{ij} = \mathrm{B}_{\mathrm{ij}}^{-1}(0) \leq V \qquad 1 \leq j \leq s$

因为 $\mathrm{B}_{\mathrm{ij}} \neq 0$，所以 $V_{ij} \neq V$， V_{ij} 是 V 的有降个 $\dfrac{1}{2}s(s-1)$ 个非平凡子空间，由chap补5，（见6、92、12.4），存在 $\alpha \in V$，且 $\alpha \notin V_{ij}$

即 $l \leq i \leq j \leq s, 0 \neq B_{ij}\alpha = \mathrm{A}_{\mathrm{i}}\alpha - \mathrm{A}_{\mathrm{j}}\alpha$

$\therefore \mathrm{A}_{\mathrm{i}}\alpha \neq \mathrm{A}_{\mathrm{j}}\alpha$

即 $\mathrm{A}_1\alpha, \mathrm{A}_2\alpha, \cdots \mathrm{A}_s\alpha$ 两两不同

P327补9 设 $\mathrm{A} \in L(V), W \leq V, \dim W = S, \mathrm{A}W = \{\mathrm{A}\alpha \mid \alpha \in W\}$

证 $\dim \mathrm{A}W + \dim(\mathrm{A}^{-1}(0) \cap W) = \dim W$

证：取 $\dim(\mathrm{A}^{-1}W) = r, \mathrm{A}^{-1}(0) \cap W$ 的基 $\alpha_1, \alpha_2, \cdots \alpha_r$

扩充为 $\alpha_1, \alpha_r \cdots \alpha_s$ 为W的基，所以同理

$\mathrm{A}W = L(\mathrm{A}\alpha_{r+1}, \cdots \mathrm{A}\alpha_s)$ 且线段无关（证法与定理不同）

所以 $\dim \mathrm{A}W = S - r = \dim W - \dim(\mathrm{A}^{-1} 0 \cap W)$ （证毕）

注，秩 $(A) + 秩(A) = n,$ 并不说明，例如

$\mathrm{A} \in L(P^3), (x_1、x_2、x_3) \to (0, x_1, x_2)$

$\therefore \mathrm{A}(P^3) = \{(0, x_1, x_2) \mid x_1, x_2, \in P\}$

$\mathrm{A}^{-1}(0) = \{0, 0, x_3 \mid x_3 \in P\} \subseteq \mathrm{A}(P^3)$

$\therefore \mathrm{A}^{-1}(0) + \mathrm{A}(P^3) = \mathrm{A}(P^3) \neq V$

P327补10： $\mathrm{A,B} \in L(V)$ 。证：秩 $(\mathrm{AB}) \geq 秩(\mathrm{A}) + 秩(\mathrm{B}) - n$

证:设$W = \mathrm{B}V$ $\qquad \dim(\mathrm{A}^{-1}(0) \cap \mathrm{B}V) \leq \dim(\mathrm{A}^{-1}(0))$

由上一题（补9，P7、110，15.3） $\mathrm{A}W = \mathrm{A}(\mathrm{B}V) = \mathrm{AB}V$

$\dim(\mathrm{AB}V) + \dim(\mathrm{A}^{-1}(0)) \cap \mathrm{B}V)$

$\geq 秩(\mathrm{B}) - \dim(\mathrm{B}^{-1}(0)) = 秩(\mathrm{B}) - (n - 秩(\mathrm{A}))$

$= 秩(\mathrm{A}) - 秩(\mathrm{B}) - n$

也可用 $\psi(\mathrm{A}) = A$ 的秩 A 的秩而秩 $(AB) \geq 秩(A) + 秩(B) - n$ 而得到。

P327补11，设 $\mathrm{A}^2 = \mathrm{A}, \mathrm{B}^2 = \mathrm{B}$ 证明① $\mathrm{A}V = \mathrm{AB}V \Leftrightarrow \mathrm{AB} = \mathrm{B}, \mathrm{BA} = \mathrm{A}$

证，设 $\mathrm{A}V = \mathrm{B}V, \forall \alpha \in V, \mathrm{B}\alpha \in \mathrm{B}V = \mathrm{A}V \therefore \exists \beta \in V$

使 $\mathrm{B}\alpha = \mathrm{A}\beta$

$\therefore \mathrm{A}B\alpha = \mathrm{A}^2\beta = \mathrm{A}\beta = \mathrm{B}\alpha \quad \therefore \mathrm{AB} = \mathrm{B}$

同理可证得 $\mathrm{BA} = \mathrm{A}$

“$\Leftarrow$”已知 $\mathrm{AB}=\mathrm{B},\mathrm{BA}=\mathrm{A}$

$\alpha\in \mathrm{A}V$，那么 $\exists\beta\in V,\alpha=\mathrm{A}\beta$

$\alpha=\mathrm{A}\beta=(\mathrm{BA})\beta=\mathrm{B}(\mathrm{A}\beta)=\mathrm{B}\alpha\in \mathrm{B}V$

$\therefore \mathrm{A}V\subseteq \mathrm{B}V$（同理可证 $\mathrm{B}V\subseteq \mathrm{A}V$，）

$\therefore \mathrm{A}V=\mathrm{B}V$

P327补11② $\mathrm{A}^{-1}(0)=\mathrm{B}^{-1}(0)\Leftrightarrow \mathrm{AB}=\mathrm{A},\mathrm{BA}=\mathrm{B}$

证：“$\Leftarrow$”已知 $\mathrm{AB}=\mathrm{A},\mathrm{BA}=\mathrm{B}$

设 $\alpha\in \mathrm{A}^{-1}(0)$，因此 $\mathrm{A}\alpha=0$

$\mathrm{B}\alpha=\mathrm{B}(\mathrm{A}\alpha)=\mathrm{B}0=0$ $\therefore \alpha\in \mathrm{B}^{-1}(0)$ 即 $\mathrm{A}^{-1}(0)\subseteq \mathrm{B}^{-1}(0)$

（同样 $\mathrm{B}^{-1}(0)\subseteq \mathrm{A}^{-1}(0)$），故 $\mathrm{A}^{-1}(0)=\mathrm{B}^{-1}(0)$

"$\Rightarrow$" 已知 $\mathrm{A}^{-1}(0)=\mathrm{B}^{-1}(0)$

任设 $2\in V$ $\because \mathrm{A}(\alpha-\mathrm{A}(\alpha))=\mathrm{A}\alpha-\mathrm{A}^2\alpha=0$

$\therefore \alpha-\mathrm{A}(\alpha)\in \mathrm{A}^{-1}(0)=\mathrm{B}^{-1}(0)$

故 $\mathrm{B}(\alpha-\mathrm{A}(\alpha))=0$ 即 $\mathrm{B}\alpha=\mathrm{BA}\alpha$ $\therefore \mathrm{B}=\mathrm{BA}$

（同理可证 A=A B）

P394.1.1

A正定 $\therefore (\alpha,\alpha)=\alpha A\alpha'\geq 0("="\Leftrightarrow \alpha=0)$非负性证得

由矩阵失去,线性性成立,再由$(\beta,\alpha)=\beta A\alpha'=(\beta A\alpha')'=\alpha' A'\beta=(\alpha,\beta)$
对称性成立，是一个内积

P394.1.2 $\left(\varepsilon_i,\varepsilon_j\right)=(0\cdots\overset{i}{1}\,0\cdots 6)A\begin{pmatrix}6\\1\\1\\9\end{pmatrix};=\alpha_{ij}$

$\therefore \varepsilon_i,\varepsilon_j,\cdots\varepsilon_n$的度量矩阵即为A

P394.1.2 $|(\alpha,\beta)|\leq|\alpha||\beta|$

$$\because(\alpha,\beta)=\sum_{i=1}^{n}\sum_{j=1}^{n}a_{ij}x_iy_j$$

$$\therefore c-s-B\text{不等式为}\,|\,(\sum_{i=1}^{n}\sum_{j=1}^{n}a_{ij}x_iy_j)|\leq\sqrt{(\sum_{i=1}^{n}\sum_{j=1}^{n}a_{ij}x_ix_j)(\sum_{i=1}^{n}\sum_{j=1}^{n}a_{ij}y_iy_j)}$$

$P393.2$ ①, α=(2,1,3,2), β=(1,2,-2,1)

$\therefore|\alpha|=\sqrt{18}=\sqrt[3]{2},|\beta|=\sqrt{10},(\alpha,\beta)=0,\therefore\alpha\perp\beta$

$\therefore\langle\alpha,\beta\rangle=\dfrac{\pi}{2}$

$P393.2$ ②, α=(1,2,2,3), β=(3,1,5,1)

$|\alpha|=\sqrt{18}=\sqrt[3]{2},|\beta|=\sqrt{36}=6,(\alpha,\beta)=18$

$\therefore(\alpha,\beta)=\text{arc cos}\dfrac{(\alpha,\beta)}{|\alpha||\beta|}=arc\ \ \cos\dfrac{18}{\sqrt[3]{2},6}=arc\ \ \cos\dfrac{\sqrt{2}}{2}=\dfrac{\pi}{4}$

$P393.2$ ③, α=(1,1,1,2), β=(3,1,-1,0)

$$|\alpha|=\sqrt{7}\qquad|\beta|=\sqrt{11}\qquad(\alpha,\beta)=3$$

$$\therefore\langle\alpha,\beta\rangle=\text{arc cos}\frac{3}{\sqrt{77}}=70°0'30"38$$

P393. 3 $\because|\alpha+\beta|\leq|\alpha|+|\beta|$

$\therefore d(\alpha,\gamma)=|\alpha-\gamma|=|(\alpha-\beta)+(\beta-\gamma)|\leq|\alpha-\beta|+|\beta-\gamma|$

$=d(\alpha,\beta)+d(\beta,\gamma)$

P393.4 在R^4中求一单位向量与(1, 1, −1), (1, −1, 1−, 1), (2, 1, 1, 3)正交

解设所求

$\alpha=(x_1,x_2,x_3,x_4)$则$\sum x_i^2=1$,且

x与各向量的内积为0得

$$\begin{cases} x_1+x_2-x_3+x_4=0 \\ x_1-x_2-x_3+x_4=0 \\ 2x_1+x_2+x_3+3x_4=0 \end{cases}$$

$$\begin{pmatrix} 1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 \\ 2 & 1 & 1 & 3 \end{pmatrix} \to \begin{pmatrix} 1 & 1 & -1 & 1 \\ 0 & -2 & 0 & 0 \\ 0 & +1 & 3 & 1 \end{pmatrix} \to \begin{pmatrix} 1 & 0 & -1 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 3 & 1 \end{pmatrix} \text{令} x_4=3, \text{得}$$

$x_1=4, x_2=0, x_3=-1$

$$\alpha=\frac{1}{\pm\sqrt{26}}(-4,0,-1,3), \quad (\text{单位化})$$

$P393.5$①证:因为$(\gamma,\alpha_i)=0, i=1.2\cdots n$,而$\alpha_1,\alpha_2\cdots\alpha_n$是一个基

$$\therefore(\gamma,\gamma)=(\gamma,\sum_{i=1}^{n}k_i\alpha_i)=\sum_{i=1}^{n}k_i(\gamma,\alpha_i)=0.$$

因此,必有$\gamma=0$.

$P393.5$②证,$\because(\gamma_1,\alpha_i)=(\gamma_2,\alpha_i),\quad i=1.2\cdots n,$

$\therefore(\gamma_1-\gamma_2,\alpha_i)=0, i=1.2\cdots n$

由第①小题:$\gamma_1-\gamma_2=0$,故$\gamma_1=\gamma_2$

$$\because(\alpha_1,\alpha_2,\alpha_3)=(\varepsilon_1,\varepsilon_2,\varepsilon_3)\frac{1}{3}\begin{pmatrix} 2 & 2 & 1 \\ 2 & -1 & -2 \\ -1 & 2 & -2 \end{pmatrix}$$

P393.6

而$\frac{1}{3}\begin{pmatrix} 2 & 2 & 1 \\ 2 & -1 & -2 \\ -1 & 2 & -2 \end{pmatrix}$是正交矩阵,所以$\alpha_1,\alpha_2,\alpha_3$是标准正交基

$P393.7$

$\alpha_1=\varepsilon_1\varepsilon_s,\alpha_2=\varepsilon_1-\varepsilon_2+\varepsilon_4/\varepsilon_3=2\varepsilon_1+\varepsilon_2+\varepsilon_3$

解$:\beta_1=\alpha_1$

$$\beta_2=\alpha_2-\frac{(\alpha_2,\beta_1)}{(\beta_1,\beta_1)}\beta_1=\alpha_2-\frac{1}{2}\beta_1=\frac{1}{2}\varepsilon_1-\varepsilon_2+\varepsilon_4-\frac{1}{2}\varepsilon_5=\frac{1}{2}(\varepsilon_1-2\varepsilon_2+2\varepsilon_4-\varepsilon_5)$$

$$\beta_3=\alpha_3-\frac{2}{2}\beta_1-\frac{1}{10}\beta_2=\varepsilon_1+\varepsilon_2+\varepsilon_3-\varepsilon_5$$

再正交化称:

$$\eta_1=\frac{1}{\sqrt{2}}(\varepsilon_1+\varepsilon_5)$$

$$\eta_2=\frac{1}{\sqrt{10}}(\varepsilon_1-2\varepsilon_2+2\varepsilon_4-\varepsilon_5)$$

$$\eta_3=\frac{1}{2}(\varepsilon_1+\varepsilon_2+\varepsilon_3-\varepsilon_5)$$

P394.8，解：

$$\begin{pmatrix}2&1&-1&1&-3\\1&1&-1&0&1\end{pmatrix}\begin{pmatrix}X_1\\X_2\\X_3\\X_4\\X_5\end{pmatrix}=0\to\begin{pmatrix}1&0&0&1&-4\\0&1&-1&-1&5\end{pmatrix}X=0$$

解出：

$$\eta_1=\begin{pmatrix}0\\1\\1\\0\\0\end{pmatrix}\qquad\eta_2=\begin{pmatrix}-1\\1\\0\\1\\0\end{pmatrix}\qquad\eta_3=\begin{pmatrix}4\\-5\\0\\0\\1\end{pmatrix}$$

Schmidt:

$$\beta_1=\begin{pmatrix}0\\1\\1\\0\\0\end{pmatrix}\qquad\beta_2=\eta_2-\frac{1}{2}\beta_1=\frac{1}{2}\begin{pmatrix}-2\\1\\-1\\2\\0\end{pmatrix}\qquad\beta_3=\eta_3+\frac{5}{2}\beta_1+\frac{13}{10}\begin{pmatrix}-2\\1\\-1\\2\\0\end{pmatrix}=\frac{1}{5}\begin{pmatrix}7\\-6\\6\\13\\5\end{pmatrix}$$

单位化便得到解空间的标准正交基：

$$\varepsilon_1=\begin{pmatrix}0\\ 1/\sqrt{2}\\ 1/\sqrt{2}\\ 0\\ 0\end{pmatrix}\qquad \varepsilon_2=\begin{pmatrix}-2/\sqrt{10}\\ 1/\sqrt{10}\\ -/\sqrt{10}\\ 2/\sqrt{10}\\ 0\end{pmatrix}\qquad \varepsilon_3=\frac{1}{\sqrt{315}}=\begin{pmatrix}7\\ -6\\ 6\\ 13\\ 5\end{pmatrix}$$

P394.9 $(f,g)=\int_{-1}^{1}f(x)g(x)dx$

已知 $\alpha_1=1,\quad \alpha_2=x,\quad \alpha_3=x^2,\quad \alpha_4=x^3$

解：$\beta_1=\alpha_1=1$

$$\beta_2=\alpha_2-\frac{(\alpha_2,\beta_1)}{(\beta_1,\beta_1)}\beta_1=x-\frac{\int_{-1}^{-}xdx}{*}x$$

$$\beta_3=\alpha_2-\frac{(\alpha_3,\beta_1)}{(\beta_1,\beta_1)}\beta_1-\frac{(\alpha_3,\beta_2)}{(\beta_2,\beta_2)}\beta_2=x^2-\frac{\frac{2}{3}}{2}1-0-=x^2-\frac{1}{3}$$

$$\beta_4=\alpha_4-\frac{(\alpha_4,\beta_1)}{(\beta_1,\beta_1)}\beta_1-\frac{(\alpha_4,\beta_2)}{(\beta_2,\beta_2)}\beta_2-\frac{(\alpha_4,\beta_3)}{(\beta_3,\beta_3)}\beta_3=\alpha_4-0-\frac{\frac{2}{5}}{\frac{2}{3}}x=x^3-\frac{3}{5}x$$

$$\text{又}\because(\beta_1,\beta_1)=2\quad |\beta_1|=\sqrt{2},\quad (\beta_2,\beta_2)=\frac{2}{3}\quad |\beta_2|=\frac{2}{\sqrt{6}}$$

$$(\beta_3,\beta_3)=\int_{-1}^{+1}(x^4-\frac{2}{3}x^2+\frac{1}{9})dx=\frac{8}{45}\quad |\beta_3|=\frac{4}{\sqrt[3]{10}}$$

$$(\beta_4,\beta_4)=\int_{-1}^{1}(x^6-\frac{6}{5}x^4+\frac{9}{25}x^2)dx=\frac{8}{175}\quad |\beta_4|=\frac{4}{\sqrt[5]{14}}$$

单位化标准正交基

$$\gamma_1=\frac{1}{\sqrt{2}},\quad \gamma_2=\frac{\sqrt{6}}{2}x,\quad \gamma_3=\frac{\sqrt{10}}{4}(3x_2-1),\quad \gamma_4=\frac{\sqrt{14}}{4}(5x^3-3x)$$

*P*396.17.4

$$A=\begin{pmatrix}-1&-3&3&-3\\-3&-1&-3&3\\3&-3&-1&-3\\-3&3&-3&-1\end{pmatrix}\qquad A4E=\begin{pmatrix}-3&-3&3&-3\\-3&3&-3&3\\3&-3&3&-3\\-3&3&-3&3\end{pmatrix}$$

$\because$秩(A+4E)=1 $\quad\therefore\lambda_1=4$至少为$Acy3$重根, 而

$-$(4+4+4)+$\lambda_2=Tr(A)=-4.\Rightarrow\lambda_2=8$

$\lambda_1=-4$解(A+4E)x=o, 即$\chi_{1-}\chi_2+x_3-x_4=0$

得正交基础体系

$$\begin{pmatrix}1\\1\\0\\0\end{pmatrix}\quad\begin{pmatrix}1\\-1\\-2\\0\end{pmatrix}\quad\begin{pmatrix}1\\-1\\1\\3\end{pmatrix}$$

单位化为

$$\frac{1}{12}\begin{pmatrix}1\\1\\0\\0\end{pmatrix}\quad\frac{1}{\sqrt{6}}\begin{pmatrix}1\\-1\\-2\\0\end{pmatrix}\quad\frac{1}{\sqrt{12}}\begin{pmatrix}1\\-1\\-\\3\end{pmatrix}$$

$\lambda_2$8解(A-8E)x=0.得解取自A+4E的一列

$$\begin{pmatrix}3\\-3\\3\\-3\end{pmatrix}$$

单位化为

$$\frac{1}{2}\begin{pmatrix}1\\-1\\1\\-1\end{pmatrix}$$

$$令T=\begin{matrix}1/\sqrt{2} & 1/\sqrt{6} & 1/\sqrt{12} & 1/2\\ 1/\sqrt{2} & -1/\sqrt{2} & -1/\sqrt{12} & -1/2\\ 0 & -2/\sqrt{6} & 1/\sqrt{12} & 1/2\\ 0 & 0 & 3/\sqrt{12} & -1/2\end{matrix}\qquad 则T'AT=T^{-1}AT=\begin{pmatrix}-4 & & & \\ & -4 & & \\ & & -4 & \\ & & & 8\end{pmatrix}$$

$P395.10.1\qquad 0\in V_1\neq\varnothing$

$$\forall\beta_1,\beta_1\in V_1\qquad \left.\begin{matrix}(\beta_1,\beta_2,\alpha)=(\beta_1,\alpha)+(\beta_2,\alpha)=0\Rightarrow\beta_1+\beta_2\in V_1\\ (k\beta_1,\alpha)=k(\beta_1,\alpha)=0\Rightarrow k\beta_1\in V\end{matrix}\right\}\therefore V_1\leq V.$$

P395.10.2 $\quad\because\alpha\neq0\qquad\therefore\alpha\notin V_1\qquad$ 故$\dim V_1\leq n-1.$

将α扩充为V的一个正交基$\alpha_1=\alpha,\alpha_2,\alpha_3\cdots\alpha_n$,那么.

$\alpha i\in V_1(i\geq2)\qquad\therefore L(\alpha_2,\alpha_3\cdots\alpha_n)\leq V_1\Rightarrow\dim V_1\geq n-1.$

$\therefore\dim V_1\geq n-1.$

P394，11①设两个基：$\varepsilon_1,\varepsilon_{2,}\cdots\varepsilon_n$及$\eta_1,\eta_2,\cdots\eta_n$,它们的度量矩阵分别为A和B,并设

$$(\eta_1,\eta_2,\cdots,\eta_n)=(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n)C$$

任设$\alpha,\beta\in V,\alpha=(\varepsilon_1,\cdots,\varepsilon_n)X_1=(\eta_1,\eta_2,\cdots,\eta_n)X_2$

$$\beta=(\varepsilon_1,\cdots,\varepsilon_n)Y_1=(\eta_1,\eta_2,\cdots,\eta_n)Y_2$$

所以$X_1=CX_2,Y_1=CY_2$

$$(\alpha,\beta)=X_2^{'}BY_2=X_1^{'}AY_1=X_2^{'}(C'AC)Y_2$$

$\therefore C'AC=B$(合同)

P394.11②，

取V的一个基$\alpha_1,\alpha_2,\cdots\alpha_n$,其度量矩阵为$A$,因为A正交,故存在矩阵C,使

C'AC=E

做基($\eta_1,\eta_2,\cdots,\eta_n$)=($\alpha_1,\alpha_2,\cdots,\alpha_n$)C,那么$\eta_1,\eta_2,\cdots\eta_n$的度量矩阵为$C'AC=E$,

因此$\eta_1,\eta_2,\cdots,\eta_n$为标准正交基.

P394.12,$\alpha_1,\alpha_2,\cdots,\alpha_m\in V\qquad \alpha_{ij}=(\alpha_i,\alpha_j)$记:

$$G(\alpha_1,\alpha_2,\cdots,\ \alpha_m)=(\alpha_{ij})_{m\times m}$$

称$G(\alpha_1,\alpha_2,\cdots,\ \alpha_m)$为$\alpha_1,\alpha_2,\cdots,\ \alpha_m$的Gram矩阵

称$|G(\alpha_1,\alpha_2,\cdots,\ \alpha_m)|$为$\alpha_1,\alpha_2,\cdots,\ \alpha_m$的Gram行列式

证明$\alpha_1,\alpha_2,\cdots,\ \alpha_m$线性无关$\Leftrightarrow\left|G(\alpha_1,\alpha_2,\cdots,\ \alpha_m)\right|\neq 0$

证:若m=1, α_1线性无关$\Leftrightarrow(\alpha_1,\ \alpha_1)>0\Leftrightarrow|G(\alpha_1)|=|\alpha_1|^2\neq 0$,成立

若$m>1$,而$|G(\alpha_1,\alpha_2,\cdots,\ \alpha_n)|=0$

不妨设$A=(\beta_1,\beta_2,\cdots,\ \beta_m)$

$$\Leftrightarrow\beta_j=\sum_{\substack{k=1\\k\neq j}}^{m}c_k\beta_k\Leftrightarrow\alpha_{ij}=\sum_{k\neq j}c_k a_{ik}=\sum_{k\neq j}c_k(\alpha_i,\alpha_k)$$

$$\Leftrightarrow(\alpha_i,\alpha_j-\sum_{k\neq j}c_k,\alpha_k)=0,\therefore\Leftrightarrow\gamma=0,i=1,2,\cdots m.$$

$$\because\gamma=\alpha_j-\sum_{k\neq j}c_k\alpha_k\in L(\alpha_1,\alpha_2,\cdots,\alpha_m),$$

$$\Leftrightarrow\alpha_j=\sum_{k\neq j}ck\alpha_k\Leftrightarrow\alpha_1,\alpha_2,\cdots,\alpha_m\text{线性相关}$$

$$|G(\alpha_1)|=|\alpha_1|^2$$

$$|G(\alpha_1,\alpha_2)|=\begin{vmatrix}(\alpha_1,\alpha_2),(\alpha_1,\alpha_2)\\(\alpha_2,\alpha_1),(\alpha_2,\alpha_2)\end{vmatrix}=\begin{vmatrix}|\alpha_1|^2 & |\alpha_2||\alpha_1|\cos\theta\\ |\alpha_1||\alpha_2|\cos\theta & |\alpha_2|^2\end{vmatrix}$$

$$=|\alpha_1|^2|\alpha_2|^2(1-\cos^2\theta)=(|\alpha_1||\alpha_2|\cos\theta)^2$$

类似地:

$$|G(\alpha_1,\alpha_2,\alpha_3)|=(\text{平行六面体积})^2$$

P394，13，设：
$$A=\begin{pmatrix}\alpha_n & \alpha_n & \cdots & \alpha_{1n}\\ 0 & \alpha_{22} & \cdots & \alpha_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ 0 & 0 & \cdots & \alpha_{nn}\end{pmatrix}$$

因为A正交，故A'A=E，令A=$(\beta_1,\beta_2,\cdots\beta_n)$

由第 1 行列，$\alpha_{11}^2=1,\alpha_{11}=\pm1$

由β_1与其余各列正交，$\beta_1\perp\beta_j$（j>1），（β_1，β_j）$=a_{11}\alpha_{1j}=0\Rightarrow a_{1j}=0(j>1)$

$$\therefore A=\begin{pmatrix}\pm1 & 0\\ 0 & A_1\end{pmatrix}$$

其中A_1仍为上三角正交矩阵，但阶数少 1，故可用归纳法给出证明，且n=1 时显然为真，由归纳法原理，证毕。

P394，14①，设$A=(\alpha_1,\alpha_2,\cdots,\alpha_n)$,则$\alpha_1,\alpha_2,\cdots,\alpha_n$做成$\mathbb{R}^n$的一个基,用Schmidt方法把它们正交化$\varepsilon_1,\varepsilon_2,\cdots\varepsilon_n$,由定理2$(P9,130,4.1)$

$$L(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_i)=L(\alpha_1,\alpha_2,\cdots,\alpha_i),\forall_i$$

$$\therefore(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n)=(\alpha_1,\alpha_2,\cdots,\alpha_n)\begin{pmatrix}t_{11} & t_{12} & \cdots & t_{1n}\\ & t_{22} & \cdots & t_{in}\\ & & \ddots & t_{n-1n}\\ & & & t_{nn}\end{pmatrix},t_{ii}>0$$

$$\text{令}Q=(\varepsilon_1,\varepsilon_2,\cdots\varepsilon_n)\text{正交},T_1=\begin{pmatrix}t_{11} & \cdots & t_{1n}\\ & \ddots & \\ 0 & & t_{nn}\end{pmatrix},T=T_1^{-1}$$

$$\therefore Q=AT_1$$

$$A=QT_1^{-1}=QT$$

$$(\text{唯一性})\text{若}A=QT=Q_2T_2$$

$\therefore Q_2^{-1}Q = T_2T^{-1}$

$\therefore$ 上三角矩阵T_2T为正交矩阵$Q_2^{-1}Q$

$\because T_2, T$的对角线皆大于0, $\therefore T_2T^{-1}$的对角线皆大于0, 由13题(见P19,138,10.1)

T_2T^{-1}=E，$\therefore$ T_2=T，满秩

$\therefore$ Q_2=Q

P394，14②，$\because$ A正交，则存在C可逆使

A=C'C

而 C 可逆，由①，有 C=QT，Q 正交 T 上三角。

$\therefore$ A=C'C=T'Q'QT=T'ET=T'T

P395，15①，A $\alpha = \alpha - 2(\eta,\alpha)\eta$ $\eta \in V$为一单位向量

$$\because (A\alpha, A\beta) = (\alpha - 2(\eta,\alpha)\eta, \beta - 2(\eta,\beta)\eta)$$

$$= (\alpha,\beta) - 2(\eta,\alpha)(\eta,\beta) - 2(\eta,\beta)(\alpha,\eta) + 4(\eta,\alpha)(\eta,\beta)(\eta,\eta)$$

$$= (\alpha,\beta) \qquad \therefore A\text{保持内积}$$

$$\text{又}A(k\alpha + l\beta) = k\alpha + l\beta - (2\eta, k\alpha + l\beta)\eta$$

$$= k(\alpha - 2(\eta,\alpha))\eta + l(\beta - 2(\eta,\beta))\eta = kA\alpha + lA\beta$$

$\therefore A$为线性的, 故A是正交变换

P395，15②，以η为起点,扩充一个标准正交基, $\varepsilon_1 = \eta, \varepsilon_2, \varepsilon_3, \cdots \varepsilon_n$

则$A\varepsilon_1 = \varepsilon_1 - 2\varepsilon_1 = -\varepsilon_1$ $\qquad A\varepsilon_i = \varepsilon_i - 0 = \varepsilon_i (i \geq 2)$

$$\therefore A(\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_n) = (\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_n)\begin{pmatrix} -1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & \ddots & \\ & & & & 1 \end{pmatrix}$$

$\therefore |A| = -1$, 为第二类的

P395，15③，$\because$ 1至少为A的$n-1$重特征值, 特征子空间V, $\dim V_1 = n-1$,

取V_1的标准正交基$\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_{n-1}$扩充为$V$的标准正交基$\varepsilon_1, \cdots, \varepsilon_{n-1}, \varepsilon_n$

$\because A\varepsilon_i = \varepsilon_i (i = 1, 2, \cdots n-1)$, 而$A\varepsilon_n$与$A\varepsilon_i$正交$(i = 12\cdots n-1)$

$\therefore A\varepsilon_n \in (L(A\varepsilon_1, A\varepsilon_2, \cdots, A\varepsilon_{n-1}))^{\perp} = (L(\varepsilon_1, \varepsilon_2, \cdots \varepsilon_n))^{\perp} = L(\varepsilon_n)$

$A\varepsilon_n = \pm\varepsilon_n (\because A\text{正交})$, 若$A\varepsilon_n = \varepsilon_n \Rightarrow \dim V_1 = n$矛盾, $\therefore A\varepsilon_n = -\varepsilon_n$

$$\forall \alpha \in V, \quad \alpha = \sum_{i-1}^{n} x_i \varepsilon_i$$

$$A\alpha = \sum_{i-1}^{n-1} x_i \varepsilon_i - x_n \varepsilon_n = \alpha - 2x_n \varepsilon_n = \alpha - 2(\varepsilon_n, \alpha)\varepsilon_n$$

是一个镜面反射

$P395,16,若A'=-1,\qquad \lambda_0为A的特征值,X_0为其特征向量$

$$X_0\neq 0,\qquad \therefore \overline{X_0}'X_0\neq 0$$

$$AX_0=\lambda_0X_0\qquad A\overline{X_0}=\overline{AX_0}=\overline{\lambda_0X_0}=\overline{\lambda_0}\,\overline{X_0}$$

$$\therefore \lambda_0\overline{X_0}'X_0=\overline{X_0}'(\lambda_0X_0)=\overline{X_0}'(AX_0)=-(\overline{X_0}'\overline{A}')X_0=-\left((\overline{AX_0})'\right)X_0$$

$$=-\left(\overline{AX_0}\right)'X_0=-\left(\overline{\lambda_0X_0}'\right)X_0=-\overline{\lambda_0}\quad(\overline{X_0}'X_0)$$

$$\therefore(由\overline{X_0}'X_0\neq 0)\quad \lambda_0=-\overline{\lambda_0}\qquad \lambda_0=0或纯虚数$$

$$|\lambda E-A|=\begin{vmatrix}\lambda-2 & 2 & 0\\ 2 & \lambda-1 & 2\\ 0 & 2 & \lambda\end{vmatrix}=\lambda^3-3\lambda^2-6\lambda+8=(\lambda-1)(\lambda-4)(\lambda+2)$$

P395，17①：

$$\lambda_1=1,\lambda_2=4,\lambda_3=-2$$

解：(A-λ_1E)X=0

(A-E)X=0,　　X=(2, 1, -2)', $\varepsilon_1=\frac{1}{3}(2,1,-2)'$

$解:(A-4E)X=0,X=(2,-2,1)',\ \ \varepsilon_2=\frac{1}{3}(2,-2,1)'$

$解:(A+2E)X=0,X=(1,2,2)',\ \ \varepsilon_2=\frac{1}{3}(1,2,2)'$

$$令T=\frac{1}{3}\begin{pmatrix}2 & 2 & 1\\ 1 & -2 & 2\\ -2 & 1 & 2\end{pmatrix}$$

$$则:T'AT=T^{-1}AT=\begin{pmatrix}1 & & \\ & 4 & \\ & & -2\end{pmatrix}$$

P395，17②，A=$\begin{pmatrix}2 & 2 & -2\\ 2 & 5 & -4\\ -2 & -4 & 5\end{pmatrix}$

解：①：$\because A-\lambda E,(\lambda用数1代)$, A-$E$的秩为1

$$\therefore|\lambda E-A|=(\lambda-1)^2(\lambda-\lambda_2),\therefore \lambda_2=Tr(A)-\lambda_1-\lambda_1=10$$

$2°,(A-E)(A-10E)=0$

$$\lambda_1=1,解:x_1+2x_2-2x_3=0,得:\eta_1=\begin{pmatrix}1\\ -1/2\\ 0\end{pmatrix},\eta_2=\begin{pmatrix}1\\ 2\\ \frac{5}{2}\end{pmatrix}$$

$$\varepsilon_1=\begin{pmatrix}2/\sqrt{5}\\-1/\sqrt{5}\\0\end{pmatrix},\qquad \varepsilon_2=\begin{pmatrix}2/\sqrt{45}\\4/\sqrt{45}\\5/\sqrt{45}\end{pmatrix}$$

$$\lambda_2=10,\text{取}A-E\text{的一列}:\eta_3=\begin{pmatrix}1\\2\\-2\end{pmatrix}\qquad \varepsilon_2=\begin{pmatrix}1/3\\2/3\\-2/3\end{pmatrix}$$

$$3°,\text{取}T=\begin{pmatrix}2/\sqrt{5}&2/\sqrt{45}&1/3\\-1/\sqrt{5}&4/\sqrt{45}&2/3\\0&5/\sqrt{45}&-2/3\end{pmatrix}$$

$$\text{则}:T'AT=T^{-1}AT=\begin{pmatrix}1&&\\&1&\\&&10\end{pmatrix}$$

$$A=\begin{pmatrix}0&0&4&1\\0&0&1&4\\4&1&0&0\\1&4&0&0\end{pmatrix}$$

P395,17③,

$$\text{解}:|A-\lambda E|=\begin{vmatrix}-\lambda&0&4&1\\0&-\lambda&1&4\\4&1&-\lambda&0\\1&4&0&-\lambda\end{vmatrix}=(5-\lambda)\begin{vmatrix}1&0&4&1\\1&-\lambda&1&4\\1&1&-\lambda&0\\1&4&0&-\lambda\end{vmatrix}=(5-\lambda)(3-\lambda)\begin{vmatrix}1&0&4&1\\1&-\lambda&1&4\\1&1&-\lambda&0\\0&1&-1&1\end{vmatrix}-$$

$$=(\lambda-3)(\lambda-5)\begin{vmatrix}1&0&4&1\\0&-\lambda&1&4\\4&1&-\lambda&0\\1&4&0&-\lambda\end{vmatrix}=(\lambda-3)(\lambda-5)\begin{vmatrix}-\lambda&-3&3\\1&\lambda-4&-1\\1&-1&1\end{vmatrix}$$

$$=(\lambda-3)(\lambda-5)\begin{vmatrix}-\lambda&-3-\lambda&3+\lambda\\1&-\lambda-3&-1-1\\1&0&0\end{vmatrix}=(\lambda-3)(\lambda-5)(\lambda+3)\begin{vmatrix}-1&1\\-\lambda-3&-2\end{vmatrix}$$

$$=(\lambda-3)(\lambda+3)(\lambda-5)(\lambda+5)$$

$$\lambda_1=3,\lambda_2=-3,\lambda_3=5,\lambda_4=-5$$

解:(A-$\lambda_1 E$)X=0

(A-3E)X=0, 得:X=$\begin{pmatrix}-1\\1\\-1\\1\end{pmatrix}$, $\varepsilon_1=(-\frac{1}{2},\frac{1}{2},-\frac{1}{2},\frac{1}{2})'$

解:(A$+3E$)X=0, 得:X=(1, -1, -1, 1)', $\therefore \varepsilon_2=(\frac{1}{2},-\frac{1}{2},-\frac{1}{2},\frac{1}{2})'$

解:(A-5E)X=0, 得:X=(1, 1, 1, 1)', $\therefore \varepsilon_3=(\frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{1}{2})'$

解:(A$+S\in$)X=0, 得:X=(1, 1, -1, -1)', $\therefore \varepsilon_4=(\frac{1}{2},\frac{1}{2},-\frac{1}{2},-\frac{1}{2})'$

令:T=$\frac{1}{2}\begin{vmatrix}-1&1&1&1\\1&-1&1&1\\-1&-1&1&-1\\1&1&1&-1\end{vmatrix}$

则:T'AT=T^{-1}AT=$\begin{pmatrix}3&&&\\&-3&&\\&&5&\\&&&-5\end{pmatrix}$

$$A=\begin{pmatrix}1&1&1&1\\1&1&1&1\\1&1&1&1\\1&1&1&1\end{pmatrix}$$

P395,17⑤:

解：秩（A）=1，$\therefore \lambda_1=0$为A的3重根(特征根)

$\lambda_1+\lambda_1+\lambda_1+\lambda_2=Tr(A), \therefore \lambda_2=4$

$\therefore A(A-4E)=0$

对于$\lambda_1=0$,解:$x_1+x_2+x_3+x_4=0$

得：

$$\alpha_1=\begin{pmatrix}1\\-1\\0\\0\end{pmatrix},\alpha_2=\begin{pmatrix}1\\1\\-2\\0\end{pmatrix},\alpha_3=\begin{pmatrix}1\\1\\1\\-3\end{pmatrix}\text{单位化}:\varepsilon_1=\begin{pmatrix}1/\sqrt{2}\\-1/\sqrt{2}\\0\\0\end{pmatrix},\varepsilon_2=\begin{pmatrix}1/\sqrt{6}\\1/\sqrt{6}\\-2/\sqrt{6}\\0\end{pmatrix},\varepsilon_3=\begin{pmatrix}1/\sqrt{12}\\1/\sqrt{12}\\1/\sqrt{12}\\-3/\sqrt{12}\end{pmatrix}$$

对于$\lambda_2=4$,其解为A的一列：$\alpha_4=\begin{pmatrix}1\\1\\1\\1\end{pmatrix},\varepsilon_4=\begin{pmatrix}1/2\\1/2\\1/2\\1/2\end{pmatrix}$

令T=$\begin{pmatrix}1/\sqrt{2} & 1/\sqrt{6} & 1/\sqrt{12} & 1/2\\ -1/\sqrt{2} & 1/\sqrt{6} & 1/\sqrt{12} & 1/2\\ 0 & -2/\sqrt{6} & 1/\sqrt{12} & 1/2\\ 0 & 0 & -3/\sqrt{12} & 1/2\end{pmatrix}$

则$T^{-1}AT=T'AT=\begin{pmatrix}0&&&\\&0&&\\&&0&\\&&&4\end{pmatrix}$

P395，18①f=X' $f=X'\begin{pmatrix}1&-2&0\\-2&2&-2\\0&-2&3\end{pmatrix}X,B\begin{pmatrix}1&-2&0\\-2&2&-2\\0&-2&3\end{pmatrix}$

另解法，作正交矩阵，H=$\begin{pmatrix}&&1\\&1&\\1&&\end{pmatrix},(H^{-1}=H'=H)$

$\therefore A=H'BH-E=\begin{Bmatrix}3&-2&0\\-2&2&-2\\0&-2&1\end{Bmatrix}E=\begin{Bmatrix}2&-2&0\\-2&1&-2\\0&-2&0\end{Bmatrix}$即为170中的$A$(见$P9,139,11,4$)

取$T=\frac{1}{9}\begin{pmatrix}2&2&1\\1&-2&2\\-2&1&2\end{pmatrix}$正交，则T'AT=$\begin{pmatrix}1&&\\&4&\\&&-2\end{pmatrix}=T'(H'BH-E)T$

$\therefore (HT)'B(HT)=\begin{pmatrix}1&&\\&4&\\&&-2\end{pmatrix}+T'ET=\begin{pmatrix}2&0&0\\0&5&0\\0&0&-1\end{pmatrix},HT=\frac{1}{3}\begin{pmatrix}-2&1&2\\1&-2&2\\2&2&1\end{pmatrix}$

$$\begin{cases} X_1 = -\frac{2}{3}y_1 + \frac{1}{3}y_2 + \frac{2}{3}y_3 \\ X_2 = \frac{1}{3}y_1 - \frac{2}{3}y_2 + \frac{2}{3}y_3 \\ X_3 = \frac{2}{3}y_1 + \frac{2}{3}y_2 + \frac{1}{3}y_3 \end{cases}$$

即令 $则 f = 2y_1^2 + 5y_2^2 - y_3^2$

$$f = X'\begin{pmatrix} 1 & -2 & 2 \\ -2 & -2 & 4 \\ 2 & 4 & -2 \end{pmatrix}X, B = \begin{pmatrix} 1 & -2 & 2 \\ -2 & -2 & 4 \\ 2 & 4 & -2 \end{pmatrix}$$

P395,18②

又∵ A=-B+3E即为 17②中的A（见P9,138,10,3）

$$取 T = \begin{pmatrix} 2/\sqrt{5} & 2/\sqrt{45} & 1/3 \\ -1/\sqrt{5} & 4/\sqrt{45} & 2/3 \\ 0 & 5/\sqrt{45} & -2/3 \end{pmatrix}, 则 T'AT = T^{-1}(3E-B)T = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 10 \end{pmatrix}$$

$$\therefore T^{-1}BT = T^{-1}(3E)T - \begin{pmatrix} 1 & & \\ & 1 & \\ & & 10 \end{pmatrix} = \begin{pmatrix} 2 & & \\ & 2 & \\ & & -7 \end{pmatrix}$$

令 $\begin{cases} x_1 = \frac{2}{\sqrt{5}}y_1 + \frac{2}{\sqrt{45}}y_2 + \frac{1}{3}y_3 \\ x_2 = -\frac{1}{\sqrt{5}}y_1 + \frac{4}{\sqrt{45}}y_2 + \frac{2}{3}y_3 \\ x_3 = \frac{5}{\sqrt{45}}y_2 - \frac{2}{3}y_3 \end{cases}$ ，则 $f = 2y_1^2 + 2y_2^2 - 7y_3^2$

$$f = X'\begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}X, B = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, A = \begin{pmatrix} B & 0 \\ 0 & B \end{pmatrix}$$

P395，18③,

$$解 |\lambda E - B| = \lambda^2 - 1 = (\lambda-1),(\lambda+1), \therefore \varepsilon_1 = \begin{pmatrix} 1/\sqrt{2} \\ 1/\sqrt{2} \end{pmatrix}, \varepsilon_2 = \begin{pmatrix} 1/\sqrt{2} \\ -1/\sqrt{2} \end{pmatrix}$$

$$令 T_1 = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}, 则 T_1 正交, 且$$

$$T_1' BT_1 = T_1^{-1}BT_1 = \frac{1}{2}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} = \frac{1}{2}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}\begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

令$T=\begin{pmatrix} T_1 & 0 \\ 0 & T_1 \end{pmatrix}$也正交，$\therefore T'AT=T^{-1}AT=\begin{pmatrix} 1 & & & \\ & -1 & & \\ & & 1 & \\ & & & -1 \end{pmatrix}$

令$\begin{cases} x_1=\frac{1}{\sqrt{2}}y_1+\frac{1}{\sqrt{2}}y_2 \\ x_2=\frac{1}{\sqrt{2}}y_1-\frac{1}{\sqrt{2}}y_2 \\ x_3=\frac{1}{\sqrt{2}}y_3+\frac{1}{\sqrt{2}}y_4 \\ x_4=\frac{1}{\sqrt{2}}y_3-\frac{1}{\sqrt{2}}y_4 \end{cases}$

则$f=y_1^2-y_2^2+y_3^2-y_4^2$

$$f=X'\begin{pmatrix} 1 & -1 & 3 & -2 \\ -1 & 1 & -2 & 3 \\ 3 & -2 & 1 & -1 \\ -2 & 3 & -1 & 1 \end{pmatrix}X=X'AX$$

P395，18④，

$$解:|\lambda E-A|=\begin{vmatrix} \lambda-1 & 1 & -3 & 2 \\ 1 & \lambda-1 & 2 & -3 \\ -3 & 2 & \lambda-1 & 1 \\ -2 & -3 & 1 & \lambda-1 \end{vmatrix}=(\lambda-1)\begin{vmatrix} 1 & 1 & -3 & 2 \\ 1 & \lambda-1 & 2 & -3 \\ 1 & 2 & \lambda-1 & 1 \\ 1 & -3 & 1 & \lambda-1 \end{vmatrix}$$

$$=(\lambda-1)(\lambda-7)\begin{vmatrix} 1 & 1 & -3 & -2 \\ 1 & \lambda-1 & 2 & -3 \\ 1 & 2 & \lambda-1 & 1 \\ 0 & 1 & -1 & 1 \end{vmatrix}=(\lambda-1)(\lambda-7)\begin{vmatrix} 1 & -2 & -3 & -1 \\ 1 & \lambda+1 & 2 & -1 \\ 1 & \lambda+1 & \lambda-1 & \lambda \\ 0 & 0 & -1 & 0 \end{vmatrix}$$

$$=(\lambda-1)(\lambda-7)(-1)(-1)(\lambda+3)\begin{vmatrix} 1 & -2 & -1 \\ 1 & \lambda+1 & -1 \\ 1 & \lambda+1 & \lambda \end{vmatrix}$$

$$=(\lambda-1)(\lambda-7)\begin{vmatrix} 1 & -2 & -1 \\ 0 & \lambda+3 & 0 \\ 0 & \lambda+3 & \lambda+1 \end{vmatrix}=(\lambda-1)(\lambda-7)(\lambda+1)(\lambda+3)$$

$\therefore \lambda_1=1,\lambda_2=7,\lambda_3=-1,\lambda_4=-3$

(A−λ_1E)X=(A−E)X=0, 得X=(1, 1, 1, 1)', $\varepsilon_1=\frac{1}{2}(1,1,1,1)'$

(A−λ_2E)X=(A−7E)X=0, 得X=(1, −1, 1, −1)', $\varepsilon_2=\frac{1}{2}(1,-1,1,-1)'$

(A−λ_3E)X=(A+E)X=0, 得X=(1, 1, −1, −1)', $\varepsilon_3=\frac{1}{2}(1,1,-1,-1)'$

(A−λ_4E)X=(A+3E)X=0, 得X=(1, −1, −1, 1)', $\varepsilon_4=\frac{1}{2}(1,-1,-1,1)'$

$$\therefore 令: T=\frac{1}{2}\begin{pmatrix}1&1&1&1\\1&-1&1&-1\\1&1&-1&-1\\1&-1&-1&1\end{pmatrix}, 则 T'AT=T^{-1}AT=\begin{pmatrix}1&&&\\&7&&\\&&-1&\\&&&-3\end{pmatrix}$$

$$\left\{\begin{pmatrix}X_1\\X_2\\X_3\\X_4\end{pmatrix}=T\begin{pmatrix}y_1\\y_2\\y_3\\y_4\end{pmatrix}=\frac{1}{2}\begin{pmatrix}1&1&1&1\\1&-1&1&-1\\1&1&-1&-1\\1&-1&-1&1\end{pmatrix}\begin{pmatrix}y_1\\y_2\\y_3\\y_4\end{pmatrix}\right., 则$$

$$f=y_1^2+7y_2^2-y_3^2-3y_4^2$$

P395,19, $\because$ A实对称，存在正交矩阵T，使

$$T'AT=T^{-1}AT=\begin{pmatrix}\lambda_1&&&\\&\lambda_2&&\\&&\ddots&\\&&&\lambda_n\end{pmatrix}=D$$

其中λ_1，$\lambda_2,\cdots\lambda_n$为$A$的所有特征根

A正交$\Leftrightarrow D$正交$\Leftrightarrow$正惯性指数=n$\Leftrightarrow \lambda_i>0(\forall_i=1,2\cdots n)$

P396.20 "充分性"，设λ_1为A的实特征根，取λ_1的单位特征向量ε_1，扩充为$\mathbb{R}^n$的标准正交基$\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n$, 取$T_1=(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n)$为正交矩阵

$$T_1^{-1}AT_1=T_1^{1}AT_1=\begin{pmatrix}\lambda_1&\alpha\\&A_1\end{pmatrix}$$

$\because|\lambda E-A|=(\lambda-\lambda_1)|\lambda E-A_1|$, 故$A_1$的特征根全为实根, 且阶数少, 故由归纳假设（n=1，显然成立），存在T_2正交。

$B_2=T_2A_1T_2$为上三角矩阵

作正交矩阵T,T_3

$$T_3=\begin{pmatrix}1&0\\0&T_2\end{pmatrix}, T=T_1T_3$$

那么, $T'AT=T^{-1}AT=T_3^{-1}(T_1^{-1}AT_1)T_3=T_3^{-1}\begin{pmatrix}\lambda_1 & \alpha\\ 0 & A_1\end{pmatrix}\begin{pmatrix}1 & 0\\ 0 & T_2\end{pmatrix}$

$$\begin{pmatrix}\lambda_1 & \alpha T_2\\ 0 & T_2^1 A_1 T_2\end{pmatrix}=\begin{pmatrix}\lambda_1 & \beta\\ 0 & B_1\end{pmatrix}$$

为上三角矩阵

"必要性",若$T'AT=T^{-1}AT=B$为上三角

$\because A,T\in\mathbb{R}^{n\times n},\therefore B\in\mathbb{R}^{n\times n}$

$\because|\lambda E-A|=|\lambda E-B|=\prod_{i=1}^{n}(\lambda-b_{ii})$全为实特征根$b_{11},b_{22},\cdots b_{nn}$,

P396，21“必要性”$T^{-1}AT=B$，则A，B相似，故特征值全部相同，

“充分性”，若A，B的特征值都由λ_1，λ_2，$\cdots\lambda_n$，

则存在，T_1，T_2正交，使

$$T_1'AT_1=T_1^{-1}AT_1=\begin{pmatrix}\lambda_1 & & & \\ & \lambda_2 & & \\ & & \ddots & \\ & & & \lambda_n\end{pmatrix},\quad T_2'BT_2=T_2'BT_2\begin{pmatrix}\lambda_1 & & & \\ & \lambda_2 & & \\ & & \ddots & \\ & & & \lambda_n\end{pmatrix}=D$$

$$\therefore T_1^{-1}AT_1=T_2^{-1}BT_2$$

令$T=T_1T_2^{-1}=T_1T_2'$也是正交的,且

$$T^{-1}AT=T_2(T_1^{-1}AT_1)T_2^{-1}=T_2DT_2^{-1}=B$$

P396,22,$A'=A,A^2=A$,证存在T正交, $T'AT=T^{-1}AT=\begin{pmatrix}1 & & & \\ & 1 & & \\ & & \ddots & \\ & & & 0\end{pmatrix}$

证:$\because$ A实对称, 故必有正交矩阵T使

$$T^{-1}AT=T'AT=\begin{pmatrix}\lambda_1 & & & \\ & \lambda_2 & & \\ & & \ddots & \\ & & & \lambda_n\end{pmatrix}$$

(其中特征值$\lambda_1\ge\lambda_2\ge\lambda_3\ge\cdots\ge\lambda_n$)

$\because A(A-E)=0$,最小多项式为$x(x-1)$的因式,$\therefore$特征多项式为$(x-1)^r x^{n-r}$

而λ_i为特征值,$X-\lambda_i\,|\,(x-1)^r X^{n-r}\Rightarrow\lambda_i=1$或0

$$\therefore\lambda_1=\lambda_2=\cdots=\lambda_r=1,\lambda_{r+1}=\cdots=\lambda_n=0$$

证毕.

$P396,23 \quad A\in L(V)$为正交变换,子空间$W\le V$为A的不变子空间

$\forall\alpha\in W^{\perp}$,由于对$\forall\beta\in W$有$A\beta\in W$(必须假设dimW有限)

$\because$ dimW有限,$\therefore$ AW=W, $\forall\gamma\in$ W, 必有$\beta\in$ W, 使Aβ=γ

$\therefore(A\alpha,\gamma)=(A\alpha,A\beta)=(\alpha,\beta)=0$

因此,$A\alpha\in W^{\perp}$

故$W^{\perp}$也是A的不变子空间

(注:若dimW=∞, V=$\left\{\alpha=(x_1,x_2,\cdots,x_n\cdots)\mid x_i\text{中有限个非}0\right\}$,$W=\left\{\alpha\in V\mid x_1=\cdots=x_r=0\right\}$

$A\alpha=(0,x_1,x_2,x_3,\cdots x_n,\cdots)$.内积为对应分量之积之和,则$A$为正交变换.

W为$A-$子空间,$W^{\perp}=\left\{\alpha\in V\mid x_{r+1}=x_{r+2}=\cdots=x_n=\cdots=0\right\}$,不是$/A-$子空间

$\because\gamma=(0,0,\overset{(r\text{个})}{\cdots},1,0,\cdots)\in W^{\perp}$,但$A\gamma=(0,\cdots,\overset{(r+1\text{个})}{0},1,0,\cdots,0)\notin W^{\perp}$)

P396、24① “必要性”,若A反对称,在标准正交基$\varepsilon_1,\varepsilon_2,\cdots\varepsilon_n$下

$A(\varepsilon_1,\cdots\varepsilon_n)=(\varepsilon_1,\cdots\varepsilon_n)A \qquad A=(a_{ij})_{n\times n}$

则:$a_{ij}=(A\varepsilon_j,\varepsilon_i)=-(\varepsilon_j,A\varepsilon_i)=-(A\varepsilon_i,\varepsilon_j)=-a_{ij}$.

$\therefore A'=-A$

“充分性”,若$A(\varepsilon_1,\cdots\varepsilon_n)=(\varepsilon_1,\cdots\varepsilon_n)A \qquad \therefore A'=-A$

$\forall\alpha=(\varepsilon_1,\cdots\varepsilon_n)X \qquad \beta=(\varepsilon_1,\cdots\varepsilon_n)Y. \qquad A\alpha,A\beta$以坐标为AX、AY。

$\therefore(A\alpha,\beta)=(AX)'Y=X'A'Y=-X'AY=-X'(AY)=-(\alpha,A\beta)$

即,A为反对称的

P396、242 设V_1为/A-子空间,A反对称。

W=$V^{\perp}$ $\quad\forall\alpha\in W \quad \forall\beta\in V_1 \quad \because$ A$\beta\in V_1$

$\therefore$(Aα, β)=(α, Aβ)=0

$\therefore A\alpha\in W$ 故W为A-子空间。

P397.25.设V=$V_1\oplus V_1^2$

必要性,若α=β+γ,($\beta\in V_1,\gamma\in V_1^2$),则$\forall\xi V_1$. $\quad\alpha-\beta\perp\beta-\xi$

$\therefore|\alpha-\xi|^2=|(\alpha-\beta)+(\beta-\xi)|^2=|\alpha-\beta|^2\ge|\alpha-\beta|^2$

即$|\alpha-\beta|\le|\alpha-\xi|$.

α在V_1的分解式, $\alpha=\alpha_1+\alpha_2 \quad \alpha_1\in V_1 \quad \alpha_2\in V_1^2$

于是$|\alpha-\alpha_1|\le|\alpha-\beta|\le|\alpha-\alpha_1|$ $\qquad$ 又$\because\beta-\alpha_1\in V_1$

充分性,取$\therefore|\alpha-\alpha_1|^2=|\alpha-\beta|^2+|\beta-\alpha_1|^2\Rightarrow|\beta-\alpha_1|=0\Rightarrow\beta=\alpha_1$必为内射影.

$P396,26$,证 1) $(V_1+V_2)^{\perp}=V_1^{\perp}\cap V_2^{\perp}$ 和 $2)(V_1\cap V_2)^{\perp}=V_1^{\perp}+V_2^{\perp}$

证 1）$\because (V_1+V_2)^{\perp} \subseteq V_1^{\perp}, V_2^{\perp} \qquad \therefore (V_1+V_2)^{\perp} \subseteq V_1^{\perp} \cap V_2^{\perp}$

反过来, $\forall \alpha \in V_1^{\perp} \cap V_2^{\perp}$, 则$\forall \beta \in V_1+V_2 \quad \beta = \beta_1+\beta_2 (\beta_i \in V_i)$

$\because \alpha \perp \beta_1, \alpha \perp \beta_2, \therefore \alpha \perp \beta_1+\beta_2 = \beta \Rightarrow \alpha \in (V_1+V_2)^{\perp}$

$\therefore V_1^{\perp} \cap V_2^{\perp} \subseteq (V_1+V_2)^{\perp} \qquad$ 故$(V_1+V_2)^{\perp} = V_1^{\perp} \cap V_2^{\perp}$

2),由于正交补是唯一的

$\because (V_1 \cap V_2)^{\perp} = \left((V_1^{\perp})^{\perp} \cap (V_2^{\perp})^{\perp}\right)^{\perp} = \left((V_1^{\perp}+V_2^{\perp})^{\perp}\right)^{\perp} = V_1^{\perp}+V_2^{\perp}$

$$P396,27 \qquad A=\begin{pmatrix} 0.39 & -1.89 \\ 0.61 & -1.80 \\ 0.93 & -1.68 \\ 1.35 & -1.50 \end{pmatrix} \qquad B=\begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

$$A'A=\begin{pmatrix} 3.2116 & -5.4225 \\ -5.4225 & 11.8845 \end{pmatrix} \qquad A'B=\begin{pmatrix} 3.28 \\ -6.87 \end{pmatrix}$$

$\therefore A'AX = A'B, \qquad |A'A| = 8.76475395 = d$

得$: d_x = 1.728585, d_y = -4.277892$

$$\therefore X = \frac{d_x}{d} = 0.197220025 \approx 0.197 \qquad M = \frac{d_y}{d} = -0.48867896 \approx -0.488$$

设$A=(\alpha_1,\alpha_2)$,故B到子空间$W=L(\alpha_1,\alpha_2)$的垂足为$0.197\alpha_1 - 0.488\alpha_2$

B到W的距离为 $|\mathrm{B}-0.197\alpha_1 + 0.488\alpha_2|$

$$=\left|\begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} 0.07683 \\ 0.12017 \\ 0.18321 \\ 0.26595 \end{pmatrix} - \begin{pmatrix} 0.92232 \\ 0.8784 \\ 0.81984 \\ 0.732 \end{pmatrix}\right| - \left|\begin{pmatrix} 0.00085 \\ 0.00143 \\ -0.00305 \\ 0.00205 \end{pmatrix}\right| = \sqrt{0.000016272} = 0.004033906 \approx 0.00403$$

P397 补 1，设λ为A（正交）的特征值，定义AX=AX，则A为正交变换

$\because AX_0 = \lambda X_0 \Rightarrow |/AX_0| = |X_0| \Rightarrow |\lambda| = 1 \Rightarrow \lambda = \pm 1, (\because \lambda \in \mathbb{R})$

P397，**补 2**， A 为 V 中正交变换，|A|=1

设A的特征值为$\lambda_1, \lambda_2, \cdots \lambda_n, \because |\lambda_i| = 1$, 及$\mathrm{f_A}(x)$是一个实系数多项式,

$\therefore \lambda_1, \lambda_2, \cdots \lambda_n$中有$k$对共轭之积为1, 剩下的n-2k个实根$\lambda_{i_1}, \lambda_{i_2}, \cdots \lambda_{i_{n-2k}}$之积为1 。

$\because \lambda_{i_s} = \pm 1, \therefore -1$的个数必为偶数个, 而dimV为奇数, 因此至少有一个特征值为实数1

P397 补 3（仿上题），∵|A|=-1，剩下的n-2k个实根之积为-1，其中必有特征值= -1。

P397,补 4：令 $r = A(k\alpha + l\beta - kA\alpha - lA\beta, \quad \because A$得内积

$$\therefore (\gamma,\gamma) = A(k\alpha + l\beta), A(k\alpha + l\beta)) - (A(k\alpha + l\beta), kA\alpha) - (A(k\alpha + l\beta), lA\beta)$$
$$- (kA\alpha, A(k\alpha + l\beta)) + (kA\alpha, kA\alpha) + (k(A\alpha, lA\beta) - (lA\beta, A(k\alpha + l\beta))$$
$$+ (lA\beta, kA\alpha) + (lA\beta, lA\beta)$$
$$= (k\alpha + l\beta, k\alpha + l\beta) - k(k\alpha + l\beta, \alpha) - l(k\alpha + l\beta, \beta) - k(\alpha, k\alpha + l\beta) + k^2(\alpha,\alpha) + kl(\alpha,\beta)$$
$$- l(\beta, k\alpha + l\beta) + kl(\beta,\alpha) + l^2(\beta,\beta)$$
$$= (k\alpha + l\beta - k\alpha - l\beta, k\alpha + l\beta - k\alpha - l\beta) = 0, \therefore r = 0$$
而 $\forall k,l,\alpha,\beta,\ A(k\alpha + l\beta) = kA\alpha + lA\beta, \therefore A \in L(V)$, 故 A 是正交变换

$P397$ 补5,"必要性": $(\beta_i,\beta_j) = (A\alpha_i, A\alpha_j) = (\alpha_i,\ \alpha_j)$

"充分性"(归纳法) $m=1$ 时, $|\alpha_1| = |\beta_1|$

作标准正交基 $\varepsilon_1 = \dfrac{1}{|\alpha_1|}\alpha_1, \varepsilon_2, \cdots,\ \varepsilon_n$ 及 $\eta_1 = \dfrac{1}{|\beta_1|}\beta_1, \eta_2, \cdots,\ \eta_n$, 则线性变换 $\mathrm{A}: \varepsilon_{\mathrm{i}} \to \eta_i$

是正交变换，则A $\alpha_1 = A|\alpha_1|, \varepsilon_1 = |\beta_1|$，$A\varepsilon_1 = \beta_1$, 而为所求设 $m-1$ 成立, 考虑m情形

由假设有正交变换 A_1，$\alpha_i \to \beta_i, \alpha_m \to \tilde{\beta}_m, i = 1,2,\cdots,m-1$，由于 A_1 保持内积及Gram矩阵，行列式的线性相关系。

$\beta_1, \cdots \beta_{m-1}, \tilde{\beta}_m$ 与 $\beta_1, \beta_2, \cdots \beta_{m-1}, \beta_n$

任何一个局部的线性关系相同，设W=L$(\beta_1, \cdots \beta_{m-1})$

$V_1 = L(\beta_1, \cdots,\ \beta_{m-1}, \tilde{\beta}) = W + L(\tilde{\beta}_m), V_2 = L(\beta_1, \cdots,\ \beta_m) = W + L(\beta_m)$

(1)若 $\tilde{\beta}_m \in W$, 则 $\beta_m \in W$, 设 W 的标准正交基 $\varepsilon_1, \varepsilon_2, \cdots,\ \varepsilon_r$

$\because (\tilde{\beta}_m, \beta_i) = (\beta_m, \beta_i) \Rightarrow \forall i (\tilde{\beta}_m, \varepsilon_i) = (\beta_m, \varepsilon_i) \Rightarrow \tilde{\beta}_m = \beta_m$, 则 A, 即已为所求

(2)若 $\tilde{\beta}_m \notin W$, 则 $\beta_m \notin W$, 设 V_1 的标准正交基 $\varepsilon_1, \cdots, \varepsilon_r, \tilde{\varepsilon}_{r+1}$, V_2 的标准正交基 $\varepsilon_1, \cdots, \varepsilon_r$, $\varepsilon_{\gamma+1}$, 分别扩充为V的标准正交基, $\cdots \tilde{\varepsilon}_{\gamma+1} \cdots \tilde{\varepsilon}_n$, 及 $\cdots \varepsilon_{\gamma+1}, \cdots \varepsilon_n$, 作线性变换/A,

$\varepsilon_i \to \varepsilon_i, \tilde{\varepsilon}_j \to \begin{pmatrix} i \le r \\ j > v \end{pmatrix}$, 是一个正交变换, 而 $\beta_{\mathrm{m}}(\widetilde{\beta_{\mathrm{m}}})$ 用 $\varepsilon_1, \cdots, \varepsilon_r, \varepsilon_{r+1}$(或 $\widetilde{\varepsilon_{r+1}}$)表示时的系数完全由 β_i, β_j 之间的内积确定, 由充分已知条件, 这些系数对应相等.

$\therefore A_2\tilde{\beta}_m = A_2(\alpha_1\varepsilon_1 + \cdots + \alpha_r\varepsilon_r + \alpha_{r+1}\tilde{\varepsilon}_{r+1}) = \alpha_1\varepsilon_1 + \alpha_2\varepsilon_2 + \cdots + \alpha_r\varepsilon_r + \alpha_{r+1}\varepsilon_{r+1} = \beta_m$

且 A_2 在 W 上不动, 即, $\mathrm{A}_2\beta_i = \beta_i (1 \le i \le r)$

取 $A = A_2A_1$ 的合成, 则: $\mathrm{A}: \alpha_{\mathrm{i}} \to \beta_i \quad (i = 1,2,\cdots m)$

且 A 为正交变换, 即为所求.

$P397$ 补6, $\because$ A实对称, $\therefore$ 存在T正交, 使

$$T'AT=T^{-1}AT=\begin{pmatrix}\lambda_1&&&\\&\lambda_2&&\\&&\ddots&\\&&&\lambda_n\end{pmatrix},\text{其中}\lambda_1\ge\lambda_2\ge\cdots\ge\lambda_n,\text{为}A\text{的特征值}$$

$\because A^2=E,\therefore A$的最小多项式为$x^2-1$的因式,故

A的特征多项式为$(x-1)^r(x+1)^{n-r}$,即A的特征值为1或-1

$\therefore$当$\lambda_i=\pm1$,因此$\lambda_1=\cdots=\lambda_r=1,\lambda_{r+1}=\cdots=\lambda_n=-1$

即:$T^{-1}AT=\begin{pmatrix}E_r&0\\0&-E_{n-r}\end{pmatrix}$

P397 补 7,作正交替换,X=TY,$\therefore X'X'=(Y'T')(TY)=Y'Y$

使$f=X'AX=\lambda_1y_1^2+\lambda_2y_2^2+\cdots+\lambda_ny_n^2,\qquad \lambda_1\le\lambda_2\le\cdots\le\lambda_n$

$\therefore f=X'AX\le\lambda_n(y_1^2+y_2^2+\cdots+y_n^2)=\lambda_nY'Y=\lambda_nX'X$

$f=X'AX\ge\lambda_1(y_1^2+y_2^2+\cdots+y_n^2)=\lambda_1Y'Y=\lambda_nX'X$,即得证

P397. 补8设$f=X'AX$,且正交替换$X=TY$,使(λ_1=λ)

$$f=\lambda y_1^2+\lambda_2y_2^2+\cdots+\lambda_ny_n^2\qquad \text{令}Y_0=\begin{pmatrix}1\\0\\\vdots\\0\end{pmatrix}\qquad \overline{X}=TY_0=\begin{pmatrix}\overline{x_1}\\\overline{x_2}\\\vdots\\\overline{x_n}\end{pmatrix}\in R^n$$

$$\therefore f(\overline{X})=f(\overline{x_1},\overline{x_2},\cdots,\overline{x_n})=\lambda=\lambda Y_0'Y_0=\lambda\left((T'\overline{X})'(T'\overline{X})\right)$$

$$=\lambda\left(\overline{X}'(TT')\overline{X}\right)=\lambda\left(\overline{X}'\overline{X}\right)=\lambda(\overline{x_1}^2+\overline{x_2}^2+\cdots+\overline{x_n}^2)$$

P397,补 **9**①,取$\eta=\alpha-\beta\ne0,\eta_0=\dfrac{1}{|\eta|}\eta$

作镜面反射,$A:\xi\to\xi-2(\eta_0\xi)\eta_0,\forall\xi$

则$A\alpha=\alpha-2\left(\dfrac{1}{|\eta|}(\alpha-\beta),\alpha\right)\eta_0=\alpha-2\left(\dfrac{1}{|\eta|}(\alpha-\beta),\alpha\right)\dfrac{1}{|\eta|}\eta$

$$\because 2\left(\frac{1}{|\eta|}(\alpha-\beta),\alpha\right)\frac{1}{|\eta|}=2\frac{(\alpha-\beta,\alpha)}{(\alpha-\beta,\alpha-\beta)}=2\frac{|\alpha|^2-(\alpha,\beta)}{|\alpha|^2-2(\alpha,\beta)+|\beta|^2}=2\frac{1-(\alpha,\beta)}{2-2(\alpha,\beta)}=1$$

$\therefore A\alpha=\alpha-\eta=\beta,\qquad$ 即为所求.

P397,补 **9**②,设正交变换A,标准正交基:$\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n\to\eta_1,\eta_2,\cdots,\eta_n$

作镜面反射$B_1:\varepsilon_1\to\eta_1,\varepsilon_i\to B_1\varepsilon_i$ (i>1)

$\therefore L(B\varepsilon_2,B\varepsilon_3,\cdots,B\varepsilon_n)=L(\varepsilon_1)^{\perp}\to L(\eta_1)^{\perp}=L(\eta_2,\eta_3,\cdots,\eta_n)$

不妨设B_K是一系列镜面反射使:

$$\varepsilon_1\to\eta_1,\cdots,\varepsilon_k\to\eta_k,\qquad \varepsilon_{k+1}\to B_k\varepsilon_{k+1},\cdots,\varepsilon_n\to B_k\varepsilon_n$$

作一镜面反射$\mathbb{C}_k:\xi_1=B_k\varepsilon_{k+1}-\eta_{k+1}\qquad \xi_0=\dfrac{1}{|\xi_1|}\xi$

$\mathbb{C}_k:\alpha\to\alpha-2(\xi_0,\alpha)\xi_0$ 使$B\varepsilon_{k+1}\to\eta_{k+1}$

$\because(\varepsilon_1,\cdots\varepsilon_k),\eta_1,\cdots\eta_k$与$\xi_1$正交，$\therefore l\mathrm{c}_{\mathrm{kj}}\eta_{\mathrm{i}}\to\eta_{\mathrm{i}}(1\le\mathrm{i}\le k)$

令$B_{k+1}=C_kB_k$是一系列镜面反射之积，且

$\varepsilon_1\to\eta_1,\cdots,\varepsilon_{\mathrm{k}}\to\eta_k,\varepsilon_{k+1}\to\eta_{k+1}$

继续下去，n 步后必存一系列反射之积|B 使

$\varepsilon_1\to\eta_1$ ，$\varepsilon_2\to\eta_2$ ，$\cdots,\varepsilon_{\mathrm{n}}\to\eta_n$

由线性变换的唯一存在性，$A=B_n$是一系列镜面反射之积

P397，补 10，设C可逆，使C'BC=E （$\because B>0$）

令A_1=C'AC，实对称，存在正交Q，使Q'AQ对角形

令 T=CQ，可逆，则

T'AT=Q'(C'AC)Q=Q'A.Q，对角形

T'BT=Q'(C'BC)Q=Q'EQ=E，对角形，（证毕）

$P398$,补11,设:$\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n$及$\eta_1,\eta_2,\cdots,\eta_n$都为标准正交基,解

$$(\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n)A=(\eta_1,\eta_2,\cdots,\eta_n)$$

$\because\varepsilon_1,\varepsilon_2,\cdots,\varepsilon_n$及$\eta_1,\eta_2,\cdots,\eta_n$的渡量矩阵都是单位矩阵$E$

任取$\alpha,\beta\in\mathbb{C}^n,\alpha=(\varepsilon_1,\varepsilon_2\cdots\varepsilon_n)X_1=(\eta_1,\eta_2\cdots\eta_n)X_2$

$$\beta=(\varepsilon_1,\varepsilon_2\cdots\varepsilon_n)Y_1=(\eta_1,\eta_2\cdots\eta_n)Y_2$$

其中$X_1=AX_2,Y_1=AY_2$

$$(\alpha,\beta)=(\sum x_i\varepsilon_i,\sum y_j\varepsilon_j)=\sum x_i\overline{y_j}(\varepsilon_i,\varepsilon_j)=X_1^{'}\overline{Y_1}=X_2^{'}A'\overline{AY_2}$$

$$=(\sum x_i^{'}\eta_i,\sum y_j^{'}\eta_j)=\sum x_i^{'}\overline{y_j^{'}}(\eta_i,\eta_j)=X_2^{'}E\overline{Y_2}$$

由X_2,Y_2的任意性，$A'\overline{A}=E$ 故$\overline{A}'A=E$,即A为酉矩阵

$P398$补12,设A为酉矩阵,λ为其特征值,$X_0\neq0,AX_0=\lambda X_0$

$$\therefore\overline{AX_0}=\overline{A}\overline{X_0}=\overline{\lambda}\overline{X_0}\qquad(\overline{AX_0})'=(\overline{\lambda}\overline{X_0})'=\overline{\lambda}'\overline{X}'_0$$

$$\therefore|\lambda|^2\ \overline{X_0}'X_0=\overline{\lambda}\overline{X_0}'\quad(\lambda X_0)=(\overline{AX_0})'(AX_0)=\overline{X_0}'(\overline{A}'A)X_0=\overline{X_0}'X_0$$

$$\because\overline{X_0}'X_0=|X_0|^2\neq0\qquad\therefore|\lambda|^2=1\qquad\text{即}|\lambda|=1$$

$P398$,补13,设A复可逆，$A=(\alpha_1,\alpha_2,\cdots,\ \alpha_n)$,基$\alpha_1,\alpha_2,\cdots,\ \alpha_n$

用Schmidt方法，将基正交化,为$\beta_1,\beta_2,\cdots,\ \beta_n$,可知

$$(\beta_1,\beta_2\cdots\beta_n)\begin{pmatrix}1&t_{12}&\cdots&t_{1n}\\0&1&\cdots&t_{2n}\\\vdots&\vdots&\ddots&\vdots\\0&0&\cdots&1\end{pmatrix}=(\alpha_1,\alpha_2,\cdots,\ \alpha_n)=(\beta_1,\beta_2,\cdots,\ \beta_n)\ T_1$$

用将β_i单位化, $\gamma_i=\frac{1}{|\beta_i|}\beta_i$ D= $\begin{pmatrix} |\beta_1|^{-1} & & & \\ & |\beta_2|^{-1} & & \\ & & \ddots & \\ & & & |\beta_n|^{-1} \end{pmatrix}$

可知标准正交基$(\gamma_1,\gamma_2,\cdots\gamma_n)=(\beta_1,\beta_2,\cdots\beta_n)D$

令$T_2=T_1^{-1}=\begin{pmatrix} 1 & t_{12}'' & \cdots & t_{1n}'' \\ 0 & 1 & \cdots & t_{2n}'' \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{pmatrix}$ $\mathrm{D}^{-1}=\begin{pmatrix} |\beta_1| & & & \\ & |\beta_2| & & \\ & & \ddots & \\ & & & |\beta_1| \end{pmatrix}$

$$\therefore A=(\alpha_1,\alpha_2,\cdots,\alpha_n)=(\beta_1,\beta_2,\cdots,\beta_n)T_1=(\gamma_1,\cdots,\gamma_n)D^{-1}T_1$$

即为上三角且对角线上全大于 0, $(t_{ii}=|\beta_i|>0)$

其次，另设A=U_3T_3，一个分解，则，UT=U_3T_3

$$\tilde{U}=U_3^{-1}U=\overline{U}_3{}'U=T_3T^{-1}$$

为上三角的酉矩阵（类假正 13 题，P9，138，10.1 练习 13）

$$\therefore \tilde{U}\text{为对角矩阵, 对角线大于}0\Rightarrow \tilde{U}=E$$

$$\therefore T_3=T, U_3=U, (\text{唯一性证毕})$$

P398，补 14， $\overline{A}'=A$, 若λ_0为特征值, 则有$X_0\neq 0, AX_0=\lambda_0 X_0$

$$\therefore \lambda_0\overline{X_0}'X_0=\overline{X_0}'(\lambda X_0)=\overline{X_0}'(AX_0)=(\overline{X_0}'A)X_0=(\overline{X_0}'\overline{A}')X_0$$

$$=\overline{(AX_0)}'X_0=\overline{(\lambda_0 X_0)}'X_0=\overline{\lambda_0 X_0}'X_0=\overline{\lambda_0}(\overline{X_0'}X_0)$$

$\because \overline{X_0}'X_0\neq 0$ $\therefore \lambda_0=\overline{\lambda_0}$ 故$\lambda_0\in\mathbb{R}$

若A有两个特征值$\lambda\neq\mu$, 且$X_1\neq 0, X_2\neq 0$, 使$AX_1=\lambda X_1, AX_2=\mu X_2$

$$\therefore \lambda\overline{X}_2{}'X_1=\overline{X}_2{}'(\lambda X_1)=\overline{X}_2{}'(AX_1)=(\overline{X}_2{}'A)X_1=(\overline{X}_2'\overline{A}')X_1$$

$$=\overline{(AX_2)}'X_1=\overline{(\mu X_2)}'X_1=\overline{\mu}\overline{X_2}'X_1=\mu(\overline{X_2}'X_1)$$

$\because \lambda\neq\mu$ $\therefore \overline{X}_2'X_1=0$

即$(X_1,X_2)=X_1'\overline{X_2}=(X_i\overline{X_2}')=\overline{X}_2'X_1=0,$ $\therefore X_1\perp X_2$