

# The local structure of a Dedekind domain

# Properties preserved and reflected by localization

# Properties preserved and reflected by localization

Property $P$	$A \text{ has } P \Rightarrow S^{-1}A \text{ has } P?$	$\bigwedge_{\mathfrak{p}} A_{\mathfrak{p}} \text{ has } P \Rightarrow A \text{ has } P?$
Integral domain	yes	no, $(\mathbb{F}_2)^\omega$
PID/PIR	yes	no, $(\mathbb{F}_2)^\omega$
Noetherian	yes	no, $(\mathbb{F}_2)^\omega$
Artinian	yes	no, $(\mathbb{F}_2)^\omega$
integrally closed	yes	yes, $(A^{\text{domain}} = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}})$
$\dim \leq n$	yes	yes, $(A^{\text{domain}} = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}})$
$I + J = K$	yes	yes
$I \cap J = K$	yes	yes
$IJ = K$	yes	yes
$I$ invertible	yes	yes, if $I$ is f.g.
Dedekind	yes	yes

# Properties preserved and reflected by localization

Property $P$	$A \text{ has } P \Rightarrow S^{-1}A \text{ has } P?$	$\bigwedge_{\mathfrak{p}} A_{\mathfrak{p}} \text{ has } P \Rightarrow A \text{ has } P?$
Integral domain	yes	no, $(\mathbb{F}_2)^\omega$
PID/PIR	yes	no, $(\mathbb{F}_2)^\omega$
Noetherian	yes	no, $(\mathbb{F}_2)^\omega$
Artinian	yes	no, $(\mathbb{F}_2)^\omega$
integrally closed	yes	yes, $(A^{\text{domain}} = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}})$
$\dim \leq n$	yes	yes, $(A^{\text{domain}} = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}})$
$I + J = K$	yes	yes
$I \cap J = K$	yes	yes
$IJ = K$	yes	yes
$I$ invertible	yes	yes, if $I$ is f.g.
Dedekind	yes	yes

To see  $A = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}}$ ,

# Properties preserved and reflected by localization

Property $P$	$A \text{ has } P \Rightarrow S^{-1}A \text{ has } P?$	$\bigwedge_{\mathfrak{p}} A_{\mathfrak{p}} \text{ has } P \Rightarrow A \text{ has } P?$
Integral domain	yes	no, $(\mathbb{F}_2)^{\omega}$
PID/PIR	yes	no, $(\mathbb{F}_2)^{\omega}$
Noetherian	yes	no, $(\mathbb{F}_2)^{\omega}$
Artinian	yes	no, $(\mathbb{F}_2)^{\omega}$
integrally closed	yes	yes, $(A^{\text{domain}} = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}})$
$\dim \leq n$	yes	yes, $(A^{\text{domain}} = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}})$
$I + J = K$	yes	yes
$I \cap J = K$	yes	yes
$IJ = K$	yes	yes
$I$ invertible	yes	yes, if $I$ is f.g.
Dedekind	yes	yes

To see  $A = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}}$ , the composition of monics  $A \hookrightarrow \bigcap_{\mathfrak{m}} A_{\mathfrak{m}} \xrightarrow{\subseteq} A_{\mathfrak{m}}$  becomes epic after localization at  $\mathfrak{m}$ ,

# Properties preserved and reflected by localization

Property $P$	$A \text{ has } P \Rightarrow S^{-1}A \text{ has } P?$	$\bigwedge_{\mathfrak{p}} A_{\mathfrak{p}} \text{ has } P \Rightarrow A \text{ has } P?$
Integral domain	yes	no, $(\mathbb{F}_2)^{\omega}$
PID/PIR	yes	no, $(\mathbb{F}_2)^{\omega}$
Noetherian	yes	no, $(\mathbb{F}_2)^{\omega}$
Artinian	yes	no, $(\mathbb{F}_2)^{\omega}$
integrally closed	yes	yes, $(A^{\text{domain}} = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}})$
$\dim \leq n$	yes	yes, $(A^{\text{domain}} = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}})$
$I + J = K$	yes	yes
$I \cap J = K$	yes	yes
$IJ = K$	yes	yes
$I$ invertible	yes	yes, if $I$ is f.g.
Dedekind	yes	yes

To see  $A = \bigcap_{\mathfrak{m}} A_{\mathfrak{m}}$ , the composition of monics  $A \hookrightarrow \bigcap_{\mathfrak{m}} A_{\mathfrak{m}} \xrightarrow{\subseteq} A_{\mathfrak{m}}$  becomes epic after localization at  $\mathfrak{m}$ , hence  $A \hookrightarrow \bigcap_{\mathfrak{m}} A_{\mathfrak{m}}$  is locally epic, hence epic.

# The local structure of a Dedekind domain

# The local structure of a Dedekind domain

**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .



# The local structure of a Dedekind domain

**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .

- 1  $D$  is a Dedekind domain.

# The local structure of a Dedekind domain

**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .

- 1  $D$  is a Dedekind domain.

# The local structure of a Dedekind domain

**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .

- 1  $D$  is a Dedekind domain.
- 2  $D$  is a PID.

# The local structure of a Dedekind domain

**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .

- 1  $D$  is a Dedekind domain.
- 2  $D$  is a PID.
- 3  $D$  is a field or  $D$  is a discrete valuation ring. (DVR)

# The local structure of a Dedekind domain

**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .

- 1  $D$  is a Dedekind domain.
- 2  $D$  is a PID.
- 3  $D$  is a field or  $D$  is a discrete valuation ring. (DVR)

# The local structure of a Dedekind domain

**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .

- ①  $D$  is a Dedekind domain.
- ②  $D$  is a PID.
- ③  $D$  is a field or  $D$  is a discrete valuation ring. (DVR)

*Proof.* [(1)  $\Rightarrow$  (2)] Any (semi)local Dedekind domain is a PID.

# The local structure of a Dedekind domain

**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .

- ①  $D$  is a Dedekind domain.
- ②  $D$  is a PID.
- ③  $D$  is a field or  $D$  is a discrete valuation ring. (DVR)

*Proof.* [(1)  $\Rightarrow$  (2)] Any (semi)local Dedekind domain is a PID.

[(2)  $\Rightarrow$  (1)] PIDs are Dedekind domains.

# The local structure of a Dedekind domain

**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .

- ①  $D$  is a Dedekind domain.
- ②  $D$  is a PID.
- ③  $D$  is a field or  $D$  is a discrete valuation ring. (DVR)

*Proof.* [(1)  $\Rightarrow$  (2)] Any (semi)local Dedekind domain is a PID.

[(2)  $\Rightarrow$  (1)] PIDs are Dedekind domains.  $\square$

**Ideal lattice of a DVR:** (Dual of an  $(\omega + 1)$ -chain.)



# The local structure of a Dedekind domain

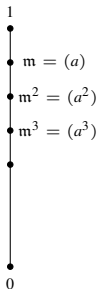
**Thm.** TFAE for a local domain  $D$  with maximal ideal  $\mathfrak{m}$ .

- ①  $D$  is a Dedekind domain.
- ②  $D$  is a PID.
- ③  $D$  is a field or  $D$  is a discrete valuation ring. (DVR)

*Proof.* [(1)  $\Rightarrow$  (2)] Any (semi)local Dedekind domain is a PID.

[(2)  $\Rightarrow$  (1)] PIDs are Dedekind domains.  $\square$

**Ideal lattice of a DVR:** (Dual of an  $(\omega + 1)$ -chain.)





Let  $X = \mathbb{C}$ , let  $A = \mathbb{C}[x]$  be the ring of polynomial functions defined on  $X$ , and let  $K = \mathbb{C}(x)$  be the field of rational functions on  $X$ .

Let  $X = \mathbb{C}$ , let  $A = \mathbb{C}[x]$  be the ring of polynomial functions defined on  $X$ , and let  $K = \mathbb{C}(x)$  be the field of rational functions on  $X$ . At each point  $\mathfrak{p} \in X$ , let  $v_{\mathfrak{p}}(f)$  count the order of the zero of  $f$  at the point  $\mathfrak{p}$ .

Let  $X = \mathbb{C}$ , let  $A = \mathbb{C}[x]$  be the ring of polynomial functions defined on  $X$ , and let  $K = \mathbb{C}(x)$  be the field of rational functions on  $X$ . At each point  $\mathfrak{p} \in X$ , let  $v_{\mathfrak{p}}(f)$  count the order of the zero of  $f$  at the point  $\mathfrak{p}$ . That is, if  $f(x) = \frac{u(x)}{w(x)}$ , and  $u(x) = a \prod (x - \mathfrak{p}_i)^{d_i}$  and  $w(x) = b \prod (x - \mathfrak{p}_i)^{e_i}$ , then  $v_{\mathfrak{p}}(u/v) = d - e$ .

Let  $X = \mathbb{C}$ , let  $A = \mathbb{C}[x]$  be the ring of polynomial functions defined on  $X$ , and let  $K = \mathbb{C}(x)$  be the field of rational functions on  $X$ . At each point  $\mathfrak{p} \in X$ , let  $v_{\mathfrak{p}}(f)$  count the order of the zero of  $f$  at the point  $\mathfrak{p}$ . That is, if  $f(x) = \frac{u(x)}{w(x)}$ , and  $u(x) = a \prod (x - \mathfrak{p}_i)^{d_i}$  and  $w(x) = b \prod (x - \mathfrak{p}_i)^{e_i}$ , then  $v_{\mathfrak{p}}(u/v) = d - e$ . The function  $v_{\mathfrak{p}}$  takes values in the discrete totally ordered group  $\mathbb{Z}$ .

If the order of  $\mathfrak{p}$  as a zero of  $f(x) = \frac{u(x)}{w(x)}$  is  $v_{\mathfrak{p}}(u/v) = n < 0$ , then we call  $\mathfrak{p}$  a pole of order  $n$  of  $f(x)$ .

Let  $X = \mathbb{C}$ , let  $A = \mathbb{C}[x]$  be the ring of polynomial functions defined on  $X$ , and let  $K = \mathbb{C}(x)$  be the field of rational functions on  $X$ . At each point  $\mathfrak{p} \in X$ , let  $v_{\mathfrak{p}}(f)$  count the order of the zero of  $f$  at the point  $\mathfrak{p}$ . That is, if  $f(x) = \frac{u(x)}{w(x)}$ , and  $u(x) = a \prod (x - \mathfrak{p}_i)^{d_i}$  and  $w(x) = b \prod (x - \mathfrak{p}_i)^{e_i}$ , then  $v_{\mathfrak{p}}(u/v) = d - e$ . The function  $v_{\mathfrak{p}}$  takes values in the discrete totally ordered group  $\mathbb{Z}$ .

If the order of  $\mathfrak{p}$  as a zero of  $f(x) = \frac{u(x)}{w(x)}$  is  $v_{\mathfrak{p}}(u/v) = n < 0$ , then we call  $\mathfrak{p}$  a pole of order  $n$  of  $f(x)$ .

The subring  $(\mathbb{C}[x])_{(x-\mathfrak{p})}$  of  $\mathbb{C}(x)$  of rational functions with no pole at  $\mathfrak{p}$  is exactly the subring of those  $f(x)$  with  $v_{\mathfrak{p}}(f) \geq 0$ .

Let  $X = \mathbb{C}$ , let  $A = \mathbb{C}[x]$  be the ring of polynomial functions defined on  $X$ , and let  $K = \mathbb{C}(x)$  be the field of rational functions on  $X$ . At each point  $\mathfrak{p} \in X$ , let  $v_{\mathfrak{p}}(f)$  count the order of the zero of  $f$  at the point  $\mathfrak{p}$ . That is, if  $f(x) = \frac{u(x)}{w(x)}$ , and  $u(x) = a \prod (x - \mathfrak{p}_i)^{d_i}$  and  $w(x) = b \prod (x - \mathfrak{p}_i)^{e_i}$ , then  $v_{\mathfrak{p}}(u/v) = d - e$ . The function  $v_{\mathfrak{p}}$  takes values in the discrete totally ordered group  $\mathbb{Z}$ .

If the order of  $\mathfrak{p}$  as a zero of  $f(x) = \frac{u(x)}{w(x)}$  is  $v_{\mathfrak{p}}(u/v) = n < 0$ , then we call  $\mathfrak{p}$  a pole of order  $n$  of  $f(x)$ .

The subring  $(\mathbb{C}[x])_{(x-\mathfrak{p})}$  of  $\mathbb{C}(x)$  of rational functions with no pole at  $\mathfrak{p}$  is exactly the subring of those  $f(x)$  with  $v_{\mathfrak{p}}(f) \geq 0$ . This is a local ring with maximal ideal consisting of the rational functions with a zero of positive order at  $\mathfrak{p}$ .



Let  $X = \mathbb{C}$ , let  $A = \mathbb{C}[x]$  be the ring of polynomial functions defined on  $X$ , and let  $K = \mathbb{C}(x)$  be the field of rational functions on  $X$ . At each point  $\mathfrak{p} \in X$ , let  $v_{\mathfrak{p}}(f)$  count the order of the zero of  $f$  at the point  $\mathfrak{p}$ . That is, if  $f(x) = \frac{u(x)}{w(x)}$ , and  $u(x) = a \prod (x - \mathfrak{p}_i)^{d_i}$  and  $w(x) = b \prod (x - \mathfrak{p}_i)^{e_i}$ , then  $v_{\mathfrak{p}}(u/v) = d - e$ . The function  $v_{\mathfrak{p}}$  takes values in the discrete totally ordered group  $\mathbb{Z}$ .

If the order of  $\mathfrak{p}$  as a zero of  $f(x) = \frac{u(x)}{w(x)}$  is  $v_{\mathfrak{p}}(u/v) = n < 0$ , then we call  $\mathfrak{p}$  a pole of order  $n$  of  $f(x)$ .

The subring  $(\mathbb{C}[x])_{(x-\mathfrak{p})}$  of  $\mathbb{C}(x)$  of rational functions with no pole at  $\mathfrak{p}$  is exactly the subring of those  $f(x)$  with  $v_{\mathfrak{p}}(f) \geq 0$ . This is a local ring with maximal ideal consisting of the rational functions with a zero of positive order at  $\mathfrak{p}$ . The ideal lattice of this ring is a dual  $(\omega + 1)$ -chain.



**Df.**

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.**

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group)

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying



**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

①  $v(fg) = v(f) + v(g)$

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

①  $v(fg) = v(f) + v(g)$

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and
- ②  $v(f + g) \geq \min\{v(f), v(g)\}$ .

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and
- ②  $v(f + g) \geq \min\{v(f), v(g)\}$ .

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and
- ②  $v(f + g) \geq \min\{v(f), v(g)\}$ .

(Sometimes we stipulate that  $v(0) = +\infty$ .)

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and
- ②  $v(f + g) \geq \min\{v(f), v(g)\}$ .

(Sometimes we stipulate that  $v(0) = +\infty$ .)

**Df.**

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and
- ②  $v(f + g) \geq \min\{v(f), v(g)\}$ .

(Sometimes we stipulate that  $v(0) = +\infty$ .)

**Df.** The *valuation ring* associated to a valuation  $v$  is  $K_v = \{a \in K \mid v(a) \geq 0\}$ .



**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and
- ②  $v(f + g) \geq \min\{v(f), v(g)\}$ .

(Sometimes we stipulate that  $v(0) = +\infty$ .)

**Df.** The *valuation ring* associated to a valuation  $v$  is  $K_v = \{a \in K \mid v(a) \geq 0\}$ .  
This is a local domain with maximal ideal  $\mathfrak{m}_v = \{a \in K \mid v(a) > 0\}$ .)

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and
- ②  $v(f + g) \geq \min\{v(f), v(g)\}$ .

(Sometimes we stipulate that  $v(0) = +\infty$ .)

**Df.** The *valuation ring* associated to a valuation  $v$  is  $K_v = \{a \in K \mid v(a) \geq 0\}$ .  
This is a local domain with maximal ideal  $\mathfrak{m}_v = \{a \in K \mid v(a) > 0\}$ .)

**Df.**

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and
- ②  $v(f + g) \geq \min\{v(f), v(g)\}$ .

(Sometimes we stipulate that  $v(0) = +\infty$ .)

**Df.** The *valuation ring* associated to a valuation  $v$  is  $K_v = \{a \in K \mid v(a) \geq 0\}$ .  
This is a local domain with maximal ideal  $\mathfrak{m}_v = \{a \in K \mid v(a) > 0\}$ .)

**Df.** For a field  $F$ , an  $F$ -valued place on  $K$  is a partial homomorphism  $\mathcal{P}: K \rightarrow F$  whose domain is a valuation subring  $K_v$  of  $K$  and whose kernel is the maximal ideal  $\mathfrak{m}_v$ .

**Df.** A *valuation ring* on a field  $K$  is a subring  $V \leq K$  such that, for every  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

**Df.** A *valuation* on a field  $K$  is a surjective function  $v: K^\times \rightarrow \langle G; +, -, 0, < \rangle$  (a totally ordered group) satisfying

- ①  $v(fg) = v(f) + v(g)$  ( $v$  is a homomorphism), and
- ②  $v(f + g) \geq \min\{v(f), v(g)\}$ .

(Sometimes we stipulate that  $v(0) = +\infty$ .)

**Df.** The *valuation ring* associated to a valuation  $v$  is  $K_v = \{a \in K \mid v(a) \geq 0\}$ .  
This is a local domain with maximal ideal  $\mathfrak{m}_v = \{a \in K \mid v(a) > 0\}$ .)

**Df.** For a field  $F$ , an  $F$ -valued *place* on  $K$  is a partial homomorphism  $\mathcal{P}: K \rightarrow F$  whose domain is a valuation subring  $K_v$  of  $K$  and whose kernel is the maximal ideal  $\mathfrak{m}_v$ .

# First conclusions

# First conclusions

- 1 The concepts “valuation”, “valuation ring”, “place” contain the same information.

# First conclusions

- 1 The concepts “valuation”, “valuation ring”, “place” contain the same information.

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .



# First conclusions

- 1 The concepts “valuation”, “valuation ring”, “place” contain the same information.
- 2 The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- 3 TFAE for subrings  $V$  of a field  $K$ :

# First conclusions

- 1 The concepts “valuation”, “valuation ring”, “place” contain the same information.
- 2 The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- 3 TFAE for subrings  $V$  of a field  $K$ :

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .(The equivalence of (1) and (2) is calghw1p2.)

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .



# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;  
the positive cone is  $(V - \{0\}) / V^\times$ ;

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;  
the positive cone is  $(V - \{0\}) / V^\times$ ;  
the valuation is  $v: K^\times \rightarrow K^\times / V^\times: x \mapsto x / V^\times$ .)

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;  
the positive cone is  $(V - \{0\}) / V^\times$ ;  
the valuation is  $v: K^\times \rightarrow K^\times / V^\times: x \mapsto x / V^\times$ .)
- ④ A valuation ring is discrete

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;  
the positive cone is  $(V - \{0\}) / V^\times$ ;  
the valuation is  $v: K^\times \rightarrow K^\times / V^\times: x \mapsto x / V^\times$ .)
- ④ A valuation ring is discrete

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;  
the positive cone is  $(V - \{0\}) / V^\times$ ;  
the valuation is  $v: K^\times \rightarrow K^\times / V^\times: x \mapsto x / V^\times$ .)
- ④ A valuation ring is discrete (has  $\mathbb{Z}$  as its value group)

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;  
the positive cone is  $(V - \{0\}) / V^\times$ ;  
the valuation is  $v: K^\times \rightarrow K^\times / V^\times: x \mapsto x / V^\times$ .)
- ④ A valuation ring is discrete (has  $\mathbb{Z}$  as its value group) iff it is Noetherian.



# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;  
the positive cone is  $(V - \{0\}) / V^\times$ ;  
the valuation is  $v: K^\times \rightarrow K^\times / V^\times: x \mapsto x / V^\times$ .)
- ④ A valuation ring is discrete (has  $\mathbb{Z}$  as its value group) iff it is Noetherian.
- ⑤ A discrete valuation ring is a local PID, hence a local Dedekind domain.

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;  
the positive cone is  $(V - \{0\}) / V^\times$ ;  
the valuation is  $v: K^\times \rightarrow K^\times / V^\times: x \mapsto x / V^\times$ .)
- ④ A valuation ring is discrete (has  $\mathbb{Z}$  as its value group) iff it is Noetherian.
- ⑤ A discrete valuation ring is a local PID, hence a local Dedekind domain.

# First conclusions

- ① The concepts “valuation”, “valuation ring”, “place” contain the same information.
- ② The valuation ring associated to a valuation on  $K$  is a valuation subring of  $K$ .
- ③ TFAE for subrings  $V$  of a field  $K$ :
  - ① The ideal lattice of  $V$  is a chain and  $K$  is the field of fractions of  $V$ .
  - ② For any  $x \in K$ , either  $x \in V$  or  $x^{-1} \in V$ .  
(The equivalence of (1) and (2) is calghw1p2.)
  - ③ There is valuation  $v$  on  $K$  and  $V = K_v$ .  
(The value group is  $G = K^\times / V^\times$ ;  
the positive cone is  $(V - \{0\}) / V^\times$ ;  
the valuation is  $v: K^\times \rightarrow K^\times / V^\times: x \mapsto x / V^\times$ .)
- ④ A valuation ring is discrete (has  $\mathbb{Z}$  as its value group) iff it is Noetherian.
- ⑤ A discrete valuation ring is a local PID, hence a local Dedekind domain.

# Existence of valuation rings

# Existence of valuation rings

Order the local subrings of  $K$  by dominance:

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ ,

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.**



# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering.

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

**Extension Lemma.**

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

**Extension Lemma.** If  $(D, \mathfrak{m}_D)$  is a local subring of  $K$ , and  $x \in K$ , then  $\mathfrak{m}_D[x] \neq D[x]$  or  $\mathfrak{m}_D[x^{-1}] \neq D[x^{-1}]$ .

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

**Extension Lemma.** If  $(D, \mathfrak{m}_D)$  is a local subring of  $K$ , and  $x \in K$ , then  $\mathfrak{m}_D[x] \neq D[x]$  or  $\mathfrak{m}_D[x^{-1}] \neq D[x^{-1}]$ .

*Proof.* Otherwise we have

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

**Extension Lemma.** If  $(D, \mathfrak{m}_D)$  is a local subring of  $K$ , and  $x \in K$ , then  $\mathfrak{m}_D[x] \neq D[x]$  or  $\mathfrak{m}_D[x^{-1}] \neq D[x^{-1}]$ .

*Proof.* Otherwise we have

$$1 = d_0 + d_1x + \cdots + d_mx^m \in \mathfrak{m}[x], \quad 1 = e_0 + e_1x^{-1} + \cdots + e_nx^{-n} \in \mathfrak{m}[x^{-1}]$$

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

**Extension Lemma.** If  $(D, \mathfrak{m}_D)$  is a local subring of  $K$ , and  $x \in K$ , then  $\mathfrak{m}_D[x] \neq D[x]$  or  $\mathfrak{m}_D[x^{-1}] \neq D[x^{-1}]$ .

*Proof.* Otherwise we have

$$1 = d_0 + d_1x + \cdots + d_mx^m \in \mathfrak{m}[x], \quad 1 = e_0 + e_1x^{-1} + \cdots + e_nx^{-n} \in \mathfrak{m}[x^{-1}]$$

for (say)  $m \geq n$  minimal.



# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

**Extension Lemma.** If  $(D, \mathfrak{m}_D)$  is a local subring of  $K$ , and  $x \in K$ , then  $\mathfrak{m}_D[x] \neq D[x]$  or  $\mathfrak{m}_D[x^{-1}] \neq D[x^{-1}]$ .

*Proof.* Otherwise we have

$$1 = d_0 + d_1x + \cdots + d_mx^m \in \mathfrak{m}[x], \quad 1 = e_0 + e_1x^{-1} + \cdots + e_nx^{-n} \in \mathfrak{m}[x^{-1}]$$

for (say)  $m \geq n$  minimal. Rewrite 2nd as  $(1 - e_0)x^n = e_1x^{n-1} + \cdots + e_n$ ,

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

**Extension Lemma.** If  $(D, \mathfrak{m}_D)$  is a local subring of  $K$ , and  $x \in K$ , then  $\mathfrak{m}_D[x] \neq D[x]$  or  $\mathfrak{m}_D[x^{-1}] \neq D[x^{-1}]$ .

*Proof.* Otherwise we have

$$1 = d_0 + d_1x + \cdots + d_mx^m \in \mathfrak{m}[x], \quad 1 = e_0 + e_1x^{-1} + \cdots + e_nx^{-n} \in \mathfrak{m}[x^{-1}]$$

for (say)  $m \geq n$  minimal. Rewrite 2nd as  $(1 - e_0)x^n = e_1x^{n-1} + \cdots + e_n$ , or  $x^n = (1 - e_0)^{-1}(e_1x^{n-1} + \cdots + e_n)$ ,

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

**Extension Lemma.** If  $(D, \mathfrak{m}_D)$  is a local subring of  $K$ , and  $x \in K$ , then  $\mathfrak{m}_D[x] \neq D[x]$  or  $\mathfrak{m}_D[x^{-1}] \neq D[x^{-1}]$ .

*Proof.* Otherwise we have

$$1 = d_0 + d_1x + \cdots + d_mx^m \in \mathfrak{m}[x], \quad 1 = e_0 + e_1x^{-1} + \cdots + e_nx^{-n} \in \mathfrak{m}[x^{-1}]$$

for (say)  $m \geq n$  minimal. Rewrite 2nd as  $(1 - e_0)x^n = e_1x^{n-1} + \cdots + e_n$ , or  $x^n = (1 - e_0)^{-1}(e_1x^{n-1} + \cdots + e_n)$ , so can reduce exponent  $m$ .

# Existence of valuation rings

Order the local subrings of  $K$  by dominance: If  $(D, \mathfrak{m}_D)$  and  $(D', \mathfrak{m}'_{D'})$  are local subrings of  $K$ , then  $(D, \mathfrak{m}_D) \leq (D', \mathfrak{m}'_{D'})$  if  $D \leq D'$  and  $\mathfrak{m}'_{D'} \cap D = \mathfrak{m}_D$ .

**Thm.** The above ordering is an inductive ordering. The maximal elements are the valuation subrings of  $K$ .

Before proving this, we need a lemma:

**Extension Lemma.** If  $(D, \mathfrak{m}_D)$  is a local subring of  $K$ , and  $x \in K$ , then  $\mathfrak{m}_D[x] \neq D[x]$  or  $\mathfrak{m}_D[x^{-1}] \neq D[x^{-1}]$ .

*Proof.* Otherwise we have

$$1 = d_0 + d_1x + \cdots + d_mx^m \in \mathfrak{m}[x], \quad 1 = e_0 + e_1x^{-1} + \cdots + e_nx^{-n} \in \mathfrak{m}[x^{-1}]$$

for (say)  $m \geq n$  minimal. Rewrite 2nd as  $(1 - e_0)x^n = e_1x^{n-1} + \cdots + e_n$ , or  $x^n = (1 - e_0)^{-1}(e_1x^{n-1} + \cdots + e_n)$ , so can reduce exponent  $m$ .  $\square$

# Proof of Theorem

# Proof of Theorem

*Proof of Theorem.*

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.)

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal.



# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ .

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ .

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ ,

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ , so  $\mathfrak{m}_D = \mathfrak{n}|_D$ ,

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ , so  $\mathfrak{m}_D = \mathfrak{n}|_D$ , so  $((D[x])_{\mathfrak{n}}, \mathfrak{n}_{\mathfrak{n}})$  is a local ring dominating  $(D, \mathfrak{m}_D)$ .

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ , so  $\mathfrak{m}_D = \mathfrak{n}|_D$ , so  $((D[x])_{\mathfrak{n}}, \mathfrak{n}_{\mathfrak{n}})$  is a local ring dominating  $(D, \mathfrak{m}_D)$ . By maximality,  $\mathfrak{m}_D = \mathfrak{n}_{\mathfrak{n}} \ni x$ ,

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ , so  $\mathfrak{m}_D = \mathfrak{n}|_D$ , so  $((D[x])_{\mathfrak{n}}, \mathfrak{n}_{\mathfrak{n}})$  is a local ring dominating  $(D, \mathfrak{m}_D)$ . By maximality,  $\mathfrak{m}_D = \mathfrak{n}_{\mathfrak{n}} \ni x$ , contradicting  $x \notin D$ .

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ , so  $\mathfrak{m}_D = \mathfrak{n}|_D$ , so  $((D[x])_{\mathfrak{n}}, \mathfrak{n}_{\mathfrak{n}})$  is a local ring dominating  $(D, \mathfrak{m}_D)$ . By maximality,  $\mathfrak{m}_D = \mathfrak{n}_{\mathfrak{n}} \ni x$ , contradicting  $x \notin D$ .

Assume that  $(D, \mathfrak{m}_D)$  is a valuation ring that is properly dominated by  $(L, \mathfrak{m}_L)$ .



# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ , so  $\mathfrak{m}_D = \mathfrak{n}|_D$ , so  $((D[x])_{\mathfrak{n}}, \mathfrak{n}_{\mathfrak{n}})$  is a local ring dominating  $(D, \mathfrak{m}_D)$ . By maximality,  $\mathfrak{m}_D = \mathfrak{n}_{\mathfrak{n}} \ni x$ , contradicting  $x \notin D$ .

Assume that  $(D, \mathfrak{m}_D)$  is a valuation ring that is properly dominated by  $(L, \mathfrak{m}_L)$ . There must exist  $x \in L - D$ .

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ , so  $\mathfrak{m}_D = \mathfrak{n}|_D$ , so  $((D[x])_{\mathfrak{n}}, \mathfrak{n}_{\mathfrak{n}})$  is a local ring dominating  $(D, \mathfrak{m}_D)$ . By maximality,  $\mathfrak{m}_D = \mathfrak{n}_{\mathfrak{n}} \ni x$ , contradicting  $x \notin D$ .

Assume that  $(D, \mathfrak{m}_D)$  is a valuation ring that is properly dominated by  $(L, \mathfrak{m}_L)$ . There must exist  $x \in L - D$ . Necessarily  $x^{-1} \in \mathfrak{m}_D \subseteq \mathfrak{m}_L$ .

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ , so  $\mathfrak{m}_D = \mathfrak{n}|_D$ , so  $((D[x])_{\mathfrak{n}}, \mathfrak{n}_{\mathfrak{n}})$  is a local ring dominating  $(D, \mathfrak{m}_D)$ . By maximality,  $\mathfrak{m}_D = \mathfrak{n}_{\mathfrak{n}} \ni x$ , contradicting  $x \notin D$ .

Assume that  $(D, \mathfrak{m}_D)$  is a valuation ring that is properly dominated by  $(L, \mathfrak{m}_L)$ . There must exist  $x \in L - D$ . Necessarily  $x^{-1} \in \mathfrak{m}_D \subseteq \mathfrak{m}_L$ . Now  $x, x^{-1} \in L$  and  $x^{-1} \in \mathfrak{m}_L$ , which is impossible.

# Proof of Theorem

*Proof of Theorem.* (Of second sentence.) Assume that  $(D, \mathfrak{m}_D)$  is maximal. If not a valuation subring, then there exists  $x \in K$  with  $x, x^{-1} \notin D$ . May assume that  $\mathfrak{m}_D[x] \leq \mathfrak{n} \prec D[x]$ . Necessarily  $\mathfrak{m}_D \subseteq \mathfrak{n}|_D \neq D$ , so  $\mathfrak{m}_D = \mathfrak{n}|_D$ , so  $((D[x])_{\mathfrak{n}}, \mathfrak{n}_{\mathfrak{n}})$  is a local ring dominating  $(D, \mathfrak{m}_D)$ . By maximality,  $\mathfrak{m}_D = \mathfrak{n}_{\mathfrak{n}} \ni x$ , contradicting  $x \notin D$ .

Assume that  $(D, \mathfrak{m}_D)$  is a valuation ring that is properly dominated by  $(L, \mathfrak{m}_L)$ . There must exist  $x \in L - D$ . Necessarily  $x^{-1} \in \mathfrak{m}_D \subseteq \mathfrak{m}_L$ . Now  $x, x^{-1} \in L$  and  $x^{-1} \in \mathfrak{m}_L$ , which is impossible.  $\square$

# Valuation rings and integral closure

**Thm.**

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.*



# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ .

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ .

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ .

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done.

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ ,

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ , so still done.

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ , so still done.

Next we argue that if  $w \notin \overline{D}$ , then there is a valuation subring of  $K$  containing  $D$  that does not contain  $w$ .

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ , so still done.

Next we argue that if  $w \notin \overline{D}$ , then there is a valuation subring of  $K$  containing  $D$  that does not contain  $w$ . First note that  $w \notin D[w^{-1}]$



# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ , so still done.

Next we argue that if  $w \notin \overline{D}$ , then there is a valuation subring of  $K$  containing  $D$  that does not contain  $w$ . First note that  $w \notin D[w^{-1}]$  (leads to integrality).

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ , so still done.

Next we argue that if  $w \notin \overline{D}$ , then there is a valuation subring of  $K$  containing  $D$  that does not contain  $w$ . First note that  $w \notin D[w^{-1}]$  (leads to integrality). Choose a maximal ideal  $\mathfrak{m}$  satisfying  $w^{-1} \in \mathfrak{n} \prec D[w^{-1}]$ .

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ , so still done.

Next we argue that if  $w \notin \overline{D}$ , then there is a valuation subring of  $K$  containing  $D$  that does not contain  $w$ . First note that  $w \notin D[w^{-1}]$  (leads to integrality). Choose a maximal ideal  $\mathfrak{m}$  satisfying  $w^{-1} \in \mathfrak{m} \prec D[w^{-1}]$ . Extend  $(D[w^{-1}]_{\mathfrak{m}}, \mathfrak{m}_{\mathfrak{m}})$  to a valuation subring  $(V, \mathfrak{m}_V)$  of  $K$ .

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ , so still done.

Next we argue that if  $w \notin \overline{D}$ , then there is a valuation subring of  $K$  containing  $D$  that does not contain  $w$ . First note that  $w \notin D[w^{-1}]$  (leads to integrality). Choose a maximal ideal  $\mathfrak{m}$  satisfying  $w^{-1} \in \mathfrak{m} \prec D[w^{-1}]$ . Extend  $(D[w^{-1}]_{\mathfrak{m}}, \mathfrak{m}_{\mathfrak{m}})$  to a valuation subring  $(V, \mathfrak{m}_V)$  of  $K$ . Necessarily  $w \notin V$ .

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ , so still done.

Next we argue that if  $w \notin \overline{D}$ , then there is a valuation subring of  $K$  containing  $D$  that does not contain  $w$ . First note that  $w \notin D[w^{-1}]$  (leads to integrality). Choose a maximal ideal  $\mathfrak{m}$  satisfying  $w^{-1} \in \mathfrak{m} \prec D[w^{-1}]$ . Extend  $(D[w^{-1}]_{\mathfrak{m}}, \mathfrak{m}_{\mathfrak{m}})$  to a valuation subring  $(V, \mathfrak{m}_V)$  of  $K$ . Necessarily  $w \notin V$ .  $\square$

# Valuation rings and integral closure

**Thm.** The integral closure  $\overline{D}$  of a subring  $D$  of a field  $K$  is the intersection of the valuation rings containing  $D$ .

*Proof.* Let  $(V, \mathfrak{m}_V)$  be any valuation subring of  $K$  containing  $D$ . We argue that  $V$  contains every element of  $\overline{D}$ . If  $u \in \overline{D}$ , then  $u^n + d_{n-1}u^{n-1} + \cdots + d_0 = 0$ . If  $u \in V$ , then done. If  $u^{-1} \in V$ , then  $u = -(d_{n-1} + d_{n-2}u^{-1} \cdots + d_0(u^{-1})^{n-1}) \in V$ , so still done.

Next we argue that if  $w \notin \overline{D}$ , then there is a valuation subring of  $K$  containing  $D$  that does not contain  $w$ . First note that  $w \notin D[w^{-1}]$  (leads to integrality). Choose a maximal ideal  $\mathfrak{m}$  satisfying  $w^{-1} \in \mathfrak{m} \prec D[w^{-1}]$ . Extend  $(D[w^{-1}]_{\mathfrak{m}}, \mathfrak{m}_{\mathfrak{m}})$  to a valuation subring  $(V, \mathfrak{m}_V)$  of  $K$ . Necessarily  $w \notin V$ .  $\square$

**Cor.** A Noetherian domain  $D$  is Dedekind iff  $D_{\mathfrak{m}}$  is a DVR for all maximal  $\mathfrak{m} \triangleleft D$ .

# Another characterization of Dedekind domains

# Another characterization of Dedekind domains

**Thm.**



## Another characterization of Dedekind domains

**Thm.** An integral domain is a Dedekind domain iff every ideal is  $1\frac{1}{2}$ -generated.

# Another characterization of Dedekind domains

**Thm.** An integral domain is a Dedekind domain iff every ideal is  $1\frac{1}{2}$ -generated.

*Proof.*

# Another characterization of Dedekind domains

**Thm.** An integral domain is a Dedekind domain iff every ideal is  $1\frac{1}{2}$ -generated.

*Proof.* “Only if” was proved on previous set of slides.

# Another characterization of Dedekind domains

**Thm.** An integral domain is a Dedekind domain iff every ideal is  $1\frac{1}{2}$ -generated.

*Proof.* “Only if” was proved on previous set of slides.

For “If”, it suffices to prove the theorem for local rings, say  $(A, \mathfrak{m})$ .

# Another characterization of Dedekind domains

**Thm.** An integral domain is a Dedekind domain iff every ideal is  $1\frac{1}{2}$ -generated.

*Proof.* “Only if” was proved on previous set of slides.

For “If”, it suffices to prove the theorem for local rings, say  $(A, \mathfrak{m})$ . Hence it suffices to prove that a local domain where every ideal is  $1\frac{1}{2}$ -generated is a PID.

## Another characterization of Dedekind domains

**Thm.** An integral domain is a Dedekind domain iff every ideal is  $1\frac{1}{2}$ -generated.

*Proof.* “Only if” was proved on previous set of slides.

For “If”, it suffices to prove the theorem for local rings, say  $(A, \mathfrak{m})$ . Hence it suffices to prove that a local domain where every ideal is  $1\frac{1}{2}$ -generated is a PID.

Choose a nonzero proper  $I \triangleleft A$ .

## Another characterization of Dedekind domains

**Thm.** An integral domain is a Dedekind domain iff every ideal is  $1\frac{1}{2}$ -generated.

*Proof.* “Only if” was proved on previous set of slides.

For “If”, it suffices to prove the theorem for local rings, say  $(A, \mathfrak{m})$ . Hence it suffices to prove that a local domain where every ideal is  $1\frac{1}{2}$ -generated is a PID.

Choose a nonzero proper  $I \triangleleft A$ . Since  $0 \neq I\mathfrak{m} \leq I$ , and  $I$  is  $1\frac{1}{2}$ -generated, there exists  $b \in I$  such that  $I = I\mathfrak{m} + (b)$ .

# Another characterization of Dedekind domains

**Thm.** An integral domain is a Dedekind domain iff every ideal is  $1\frac{1}{2}$ -generated.

*Proof.* “Only if” was proved on previous set of slides.

For “If”, it suffices to prove the theorem for local rings, say  $(A, \mathfrak{m})$ . Hence it suffices to prove that a local domain where every ideal is  $1\frac{1}{2}$ -generated is a PID.

Choose a nonzero proper  $I \triangleleft A$ . Since  $0 \neq I\mathfrak{m} \leq I$ , and  $I$  is  $1\frac{1}{2}$ -generated, there exists  $b \in I$  such that  $I = I\mathfrak{m} + (b)$ . By NAK,  $I = (b)$ .



## Another characterization of Dedekind domains

**Thm.** An integral domain is a Dedekind domain iff every ideal is  $1\frac{1}{2}$ -generated.

*Proof.* “Only if” was proved on previous set of slides.

For “If”, it suffices to prove the theorem for local rings, say  $(A, \mathfrak{m})$ . Hence it suffices to prove that a local domain where every ideal is  $1\frac{1}{2}$ -generated is a PID.

Choose a nonzero proper  $I \triangleleft A$ . Since  $0 \neq I\mathfrak{m} \leq I$ , and  $I$  is  $1\frac{1}{2}$ -generated, there exists  $b \in I$  such that  $I = I\mathfrak{m} + (b)$ . By NAK,  $I = (b)$ .  $\square$