

Real Analysis - Homework solutions

Chris Monico, May 2, 2013

1.1 (a) Rings (resp. σ -rings) are closed under finite (resp. countable) intersections.

(b) If \mathcal{R} is a ring (resp. σ -ring) then \mathcal{R} is an algebra (resp. σ -algebra) iff $X \in \mathcal{R}$.

(c) If \mathcal{R} is a (nonempty) σ -ring then $\{E \subset X : E \in \mathcal{R} \text{ or } E^c \in \mathcal{R}\}$ is a σ -algebra.

(d) If \mathcal{R} is a σ -ring, then $\{E \subset X : E \cap F \in \mathcal{R} \text{ for all } F \in \mathcal{R}\}$ is a σ -algebra.

Solution:

(a) If \mathcal{R} is a ring and $E_1, E_2 \in \mathcal{R}$, then since \mathcal{R} is closed under differences, $E_1 - (E_1 - E_2) \in \mathcal{R}$. But

$$E_1 - (E_1 - E_2) = E_1 - (E_1 \cap E_2^c) = E_1 \cap (E_1^c \cup E_2) = E_1 \cap E_2.$$

It follows inductively that \mathcal{R} is closed under finite intersections. Suppose now that \mathcal{R} is a σ -ring and $\{E_n\} \subset \mathcal{R}$. Let $A = \bigcup E_j$ and $\widetilde{E}_n = A - E_n$. Then $\widetilde{E}_n \in \mathcal{R}$ for all $n \geq 1$ and so $F = E_1 - \bigcup_{j=2}^{\infty} \widetilde{E}_j$ is also in \mathcal{R} . But

$$F = E_1 \cap \left(\bigcap_{j=2}^{\infty} \widetilde{E}_j^c \right) = E_1 \cap \left(\bigcap_{j=2}^{\infty} (A^c \cup E_j) \right) = \bigcap_{j=2}^{\infty} ((E_1 \cap A^c) \cup (E_1 \cap E_j)) = \bigcap_{j=2}^{\infty} (E_1 \cap E_j) = \bigcap_{j=1}^{\infty} E_j.$$

(b) If \mathcal{R} is a ring (resp. σ -ring) and $X \in \mathcal{R}$, then for all $E \in \mathcal{R}$ we have $E^c = X - E \in \mathcal{R}$ so \mathcal{R} is closed under complements and therefore an algebra (resp. σ -algebra). On the other hand if \mathcal{R} is an algebra (resp. σ -algebra), then it's nonempty so there exists $E \in \mathcal{R}$ and hence $X = E \cup E^c \in \mathcal{R}$.

(c) Suppose \mathcal{R} is a nonempty σ -ring and $\mathcal{M} = \{E \subset X : E \in \mathcal{R} \text{ or } E^c \in \mathcal{R}\}$. Clearly \mathcal{M} is closed under complements. Suppose that $\{E_n\} \subset \mathcal{M}$. By part (a), \mathcal{R} is closed under countable intersections so $A = \bigcap_{j \geq 1} E_j^c \in \mathcal{R}$. Since \mathcal{R} is closed under countable unions, $B = \bigcup_{j \geq 1} E_j \in \mathcal{R}$. Now

$$\begin{aligned} \bigcup_{j \geq 1} E_j &= \left(\bigcup_{\substack{j \geq 1 \\ E_j^c \in \mathcal{R}}} E_j \right) \cup \left(\bigcup_{\substack{j \geq 1 \\ E_j \in \mathcal{R}}} E_j \right) \\ &= \left(\left(\bigcap_{\substack{j \geq 1 \\ E_j^c \in \mathcal{R}}} E_j^c \right) \cap \left(\bigcup_{\substack{j \geq 1 \\ E_j \in \mathcal{R}}} E_j \right) \right)^c \\ &= (A - B)^c. \end{aligned}$$

Since $A, B \in \mathcal{R}$ and \mathcal{R} is closed under differences, $A - B \in \mathcal{R}$, hence $\bigcup E_j = (A - B)^c \in \mathcal{M}$. Therefore \mathcal{M} is also closed under countable unions, hence it's a σ -algebra.

(d) Suppose \mathcal{R} is a σ -ring and $\mathcal{A} = \{E \subset X : E \cap F \in \mathcal{R} \text{ for all } F \in \mathcal{R}\}$. Suppose $E \in \mathcal{A}$ and let $F \in \mathcal{R}$. Then $E \cap F \in \mathcal{R}$ and since \mathcal{R} is closed under differences, $E^c \cap F = F - E = F - (E \cap F) \in \mathcal{R}$, and therefore \mathcal{A} is closed under complements. If $\{E_n\} \subset \mathcal{A}$ and $F \in \mathcal{R}$ then $E_n \cap F \in \mathcal{R}$ and so $(\bigcup E_n) \cap F = \bigcup (E_n \cap F) \in \mathcal{R}$ for all n , so \mathcal{A} is closed under countable unions as well and therefore is a σ -algebra.

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