

Lebesgue spaces

Exercises

Exercise 1.1 (Measurability). Let W be a nonmeasurable subset of $D := (0, 1)$. Let $f : W \rightarrow \mathbb{R}$ be defined by $f(x) := 1$ if $x \in D \setminus W$ and $f(x) := 0$ if $x \in W$. (i) Is f measurable? (ii) Assume that there is a measurable subset $V \subset W$ s.t. $|V| > 0$. Compute $\sup_{x \in D} f(x)$, $\text{ess sup}_{x \in D} f(x)$, $\inf_{x \in D} f(x)$, $\text{ess inf}_{x \in D} f(x)$. (iii) Is f a member of $L^\infty(D)$? (iv) Assume now that W has zero measure (hence, W is measurable). Compute $\inf_{x \in D} f(x)$ and $\text{ess inf}_{x \in D} f(x)$.

Exercise 1.2 (Measurability and equality a.e.). Prove Corollary 1.11. (*Hint:* consider the sets $A_r := \{x \in D \mid f(x) > r\}$ and $B_r := \{x \in D \mid g(x) > r\}$ for all $r \in \mathbb{R}$, and show that $B_r = (A_r \cap (A_r \setminus B_r)^c) \cup (B_r \setminus A_r)$.)

Exercise 1.3 (Lebesgue's theorem). Let $D := (-1, 1)$. Let $(f_n)_{n \in \mathbb{N}}$ be a sequence of functions in $L^1(D)$ and let $g \in L^1(D)$. Assume that $f_n \rightarrow f$ a.e. in D . Propose a counterexample to show that the assumption " $|f_n| \leq g$ a.e. for all $n \in \mathbb{N}$ " cannot be replaced by " $f_n \leq g$ a.e. for all $n \in \mathbb{N}$ " in Lebesgue's dominated convergence theorem.

Exercise 1.4 (Compact support). Let $D := (0, 1)$ and $f(x) := 1$ for all $x \in D$. What is the support of f in D ? Is the support compact?

Exercise 1.5 (Pointwise limit of measurable functions). Let D be a measurable set in \mathbb{R}^d . Let $f_n : D \rightarrow \mathbb{R}$ for all $n \in \mathbb{N}$ be real-valued measurable functions. (i) Show that $\limsup_{n \in \mathbb{N}} f_n$ and $\liminf_{n \in \mathbb{N}} f_n$ are both measurable. (*Hint:* recall that $\limsup_{n \in \mathbb{N}} f_n(x) := \inf_{k \in \mathbb{N}} \sup_{h \geq k} f_h(x)$ and $\liminf_{n \in \mathbb{N}} f_n(x) := \sup_{k \in \mathbb{N}} \inf_{h \geq k} f_h(x)$ for all $x \in D$.) (ii) Let $f : D \rightarrow \mathbb{R}$. Assume that $f_n(x) \rightarrow f(x)$ for every $x \in D$. Show that f is measurable. (iii) Let $f : D \rightarrow \mathbb{R}$. Assume that $f_n(x) \rightarrow f(x)$ for a.e. $x \in D$. Show that f is measurable.

Exercise 1.6 (Operations on measurable functions). The objective of this exercise is to prove Theorem 1.6. Let $f : D \rightarrow \mathbb{R}$ and $g : D \rightarrow \mathbb{R}$ be two measurable functions and let $\lambda \in \mathbb{R}$. (i) Show that λf is measurable. (*Hint:* use Lemma 1.9.) (ii) Idem for $|f|$. (iii) Idem for $f + g$. (iv) Idem for $f g$. (*Hint:* observe that $f g = \frac{1}{2}(f + g)^2 - \frac{1}{2}(f - g)^2$.)

Lebesgue Integration Exercises And Solutions

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