

Homework 14

114. Suppose Γ is a countable group and (H, π) is a unitary representation on a separable Hilbert space. Find a unitary $u \in B(\ell^2 \Gamma \otimes H)$ intertwining $\lambda \otimes \pi$ and $\lambda \otimes 1$, i.e. $u(\lambda_g \otimes \pi_g) = (\lambda_g \otimes 1)u$ for all $g \in \Gamma$.

Proof. Define $u \in B(\ell^2 \Gamma \otimes H)$ by $u(\delta_g \otimes \xi) := \delta_g \otimes \pi_{g^{-1}} \xi$ for $g \in \Gamma$ and $\xi \in H$. This defines a unitary operator, since π is a unitary representation. We will check that u intertwines $\lambda \otimes \pi$ and $\lambda \otimes 1$. For $h \in \Gamma$ and $\xi \in H$, we have

$$\begin{aligned} u(\lambda_g \otimes \pi_g)(\delta_h \otimes \xi) &= u(\delta_{gh} \otimes \pi_g \xi) \\ &= \delta_{gh} \otimes \pi_{h^{-1}} \xi \\ &= (\lambda_g \otimes 1)(\delta_h \otimes \pi_{h^{-1}} \xi) \\ &= (\lambda_g \otimes 1)u(\delta_h \otimes \xi). \end{aligned}$$

□

115. (2) In the notes, the measure on \mathcal{R} induced by μ is defined to be $\nu = \theta_*(\mu \times \gamma)$. Therefore, θ is certainly a bijective isomorphism of measure spaces $X \times \Gamma \rightarrow \mathcal{R}$.
- (1) For $\eta \in L^2 \mathcal{R}$ and $(x, g) \in X \times \Gamma$, define $v\eta(x, g) = \eta \circ \theta$. Then for all $\eta, \xi \in L^2 \mathcal{R}$, we have $\int (v\eta)(v\xi) d(\mu \times \gamma) = \int \eta \circ \theta \xi \circ \theta d(\mu \times \gamma) = \int \eta \xi d\nu$, so v is an isometry. Since θ is a bijection, $v^* \eta = \eta \circ \theta^{-1}$, and so $vv^* = 1_{L^2(X \times \Gamma)}$ and $v^*v = 1_{L^2 \mathcal{R}}$.
- (3) Let $\eta \in L^2 \mathcal{R}$ and $(x, g) \in X \times \Gamma$. We compute:

$$\begin{aligned} M_f v\eta(x, g) &= f(x) v\eta(x, g) \\ &= f(x) \eta(x, g^{-1}x) \\ &= \lambda(f) \eta(x, g^{-1}x) \\ &= v\lambda(f) \eta(x, g) \end{aligned}$$

- (4) Again, we have

$$\begin{aligned} u_g v\eta(x, h) &= v\eta(g^{-1}x, g^{-1}h) \\ &= \eta(g^{-1}x, h^{-1}x) \\ &= \chi_{gX}(x) \eta(\varphi_g^{-1}(x), h^{-1}x) \\ &= L_{\varphi_g} \eta(x, h^{-1}x) \\ &= u L_{\varphi_g} \eta(x, h) \end{aligned}$$

- (5) Because $L^\infty(X, \mu) \trianglelefteq \Gamma = (\{u_g\} \cup \{M_f\})''$ and v is unitary, we have $v^*(L^\infty(X, \mu) \trianglelefteq \Gamma)v \subseteq L\mathcal{R}''$. Since $L\mathcal{R}$ is a von Neumann algebra, it is already its own bicommutant, giving the desired containment.
- (6) The point of problems 92 and 93 was to show that the commutant of $L^\infty(X, \mu) \trianglelefteq \Gamma$ is itself a kind of right semidirect product, generated by the right multipliers $(W_f)_{f \in L^\infty}$ and $(n_g)_{g \in \Gamma}$, with $W_f v\eta(x, g) = f(g^{-1}x) \eta(x, g)$ and $n_g v\eta(x, h) = v\eta(x, hg)$. Therefore, it suffices to show that for all $f \in L^\infty$ and $g \in \Gamma$, we have $v^* W_f v, v^* n_g v \in R\mathcal{R}$. The proof is analagous to the previous two parts. Observe:

$$\begin{aligned} W_f v\eta(x, g) &= f(g^{-1}x) v\eta(x, g) \\ &= f(g^{-1}(x)) \eta(x, g^{-1}(x)) \\ &= \rho(f) \eta(x, g^{-1}x) \\ &= v\rho(f) \eta(x, g) \end{aligned}$$

and

$$\begin{aligned}
 n_g v \eta(x, h) &= v \eta(x, hg) \\
 &= \eta(x, g^{-1} h^{-1} x) \\
 &= \eta(x, \varphi_g^{-1}(h^{-1}(x))) \\
 &= R_{\varphi_g} \eta(x, h^{-1} x) \\
 &= v R_{\varphi_g}(x, h)
 \end{aligned}$$

(7) Analogous to (5), we obtain $(v^*(L^\infty(X, \mu) \trianglelefteq \Gamma)v)' = v^*(L^\infty(X, \mu) \trianglelefteq \Gamma)'v \subseteq R\mathcal{R} \subseteq L\mathcal{R}'$, so $v^*(L^\infty(X, \mu) \trianglelefteq \Gamma)v \supseteq L\mathcal{R}$, completing the proof.

116. For each $f \in L^\infty(X, \mu) \subseteq L\mathcal{R}$, we have

$$(f \cdot \xi)(x, y) = f(x) \xi(x, y)$$

and for $g \in JAJ \subseteq L\mathcal{R}' = R\mathcal{R}$ we have

$$(g \cdot \xi)(x, y) = g(y) \xi(x, y).$$

Then we have $A \subseteq L^\infty\mathcal{R}$ and $JAJ \subseteq L^\infty\mathcal{R}$, by viewing $f \in A$ as $f \otimes 1 \in L^\infty\mathcal{R}$, and viewing $g \in JAJ$ as $1 \otimes g \in L^\infty\mathcal{R}$. Thus $A \cup JAJ \subseteq L^\infty(\mathcal{R})$, and now we show the other inclusion. Since both are SOT-closed, it suffices to show that $A \cup JAJ$ is SOT-dense in $L^\infty\mathcal{R}$. To do this we just need to show that the linear span of functions of the form $(f \otimes 1)(1 \otimes g)$ for $f, g \in L^\infty(X, \mu)$ are SOT-dense in $L^\infty\mathcal{R}$. Linear combinations of indicators are norm-dense in L^∞ , so it suffices to show that the linear span of indicators of rectangles is SOT-dense in indicators of \mathcal{R} -measurable sets.

In the notation of the last problem, we have $v^*L^\infty(\mathcal{R}, \nu)v = L^\infty(X \times \Gamma, \mu \times \gamma)$. There, up to null sets, all measurable sets are the countable union of measurable rectangles, since Γ is countable. In particular, if $S \subseteq \mathcal{R}$ and T_n is a sequence of indicator functions converging pointwise to $\chi_{\theta^{-1}(S)}$ from below, then for every $f \in L^2(\mu \times \gamma)$, we have $|f|^2 d\nu$ a finite measure absolutely continuous with respect to ν , so $\|T_n f\|_2^2 \rightarrow \|\chi_{\theta^{-1}(S)} f\|_2^2$. Finally, if $R \subseteq X \times \Gamma$ is a rectangle, then so is $\theta(R)$, so the linear span of indicators of rectangles is also SOT-dense in $L^\infty\mathcal{R}$, as desired.